8-2014

The Significance of Dolomitized Hunton Strata in the Kinta and Bonanza Fields of the Arkoma Basin

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Geology

by

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Arkansas Tech University
Bachelor of Science in Geology, 2011

August 2014
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

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ABSTRACT

The Hunton Group has been a prolific hydrocarbon-producing reservoir across much of Oklahoma and western Arkansas. The group is a Silurian-Devonian aged interval that is comprised of sequences of limestone, dolomite, and calcareous shale. The group is divided into several formations. The subdivisions include the Chimneyhill Subgroup, Henryhouse, Haragan and Bois d'Arc Formations. Reservoir quality in the Hunton Group is significantly dependent upon the diagenetic events and depositional environments of the sediments. Most hydrocarbon production, from within the Hunton Group, comes from members that have undergone dolomite replacement of the parent limestone.

The higher amounts of porosity and permeability are associated with secondary dissolution in packstones and grainstones. The changes in facies and diagenesis are major factors in reservoir productivity. Understanding the relationships between reservoir facies and diagenesis is crucial for the successful development of these fields. A better understanding of the origin and diagenesis of these dolomite horizons will be very beneficial in the further development of the Kinta and Bonaza Fields.

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INTRODUCTION

Shallow marine carbonate rocks of Silurian-Devonian age are present in the subsurface of western Arkansas and throughout most of Oklahoma. These carbonate rocks form what is known as the Hunton Group. Deposition was continuous throughout much of the Silurian and Devonian however; variations in Hunton thickness are due to two major uplifts during and after deposition. The Early to Late Devonian time of exposure significantly altered the Hunton paleotopographic surface and created regional unconformities.

Carbonate reservoirs have proven to be some the most complex and productive reservoirs around the world. The Hunton Group has been a prolific hydrocarbon-producing reservoir across much Oklahoma and into western Arkansas. By analyzing well logs, thin sections, cores, and samples, it is evident that changes in facies and diagenesis play an important role in Hunton reservoir productivity, as does dolomitization, fracturing and dissolution. Most hydrocarbon production, from within the Hunton Group, comes from members that have undergone dolomitic replacement of the parent limestone. The greater amounts of porosity and permeability are associated with the secondary dissolution in packstones and grainstones. Understanding the relationship between the diagenetic events and reservoir productivity provides geologist with the ability to more accurately predict profitable zones of production.

Study Area

The study area encompasses roughly a 2,160 square miles area located in the western part of the Arkansas River Valley and extends into the eastern part of Oklahoma. This area includes portions of Sebastian County, Arkansas as well as Sequoyah, Haskell, and Le Flore counties in Oklahoma. The study area includes Townships 5-10 North and Ranges 28 to 32 West in western

Arkansas and Townships 7-12 North and Ranges 22-27 East in eastern Oklahoma. Figure 1 shows the study area in relation to local cities and the border of Arkansas and Oklahoma.

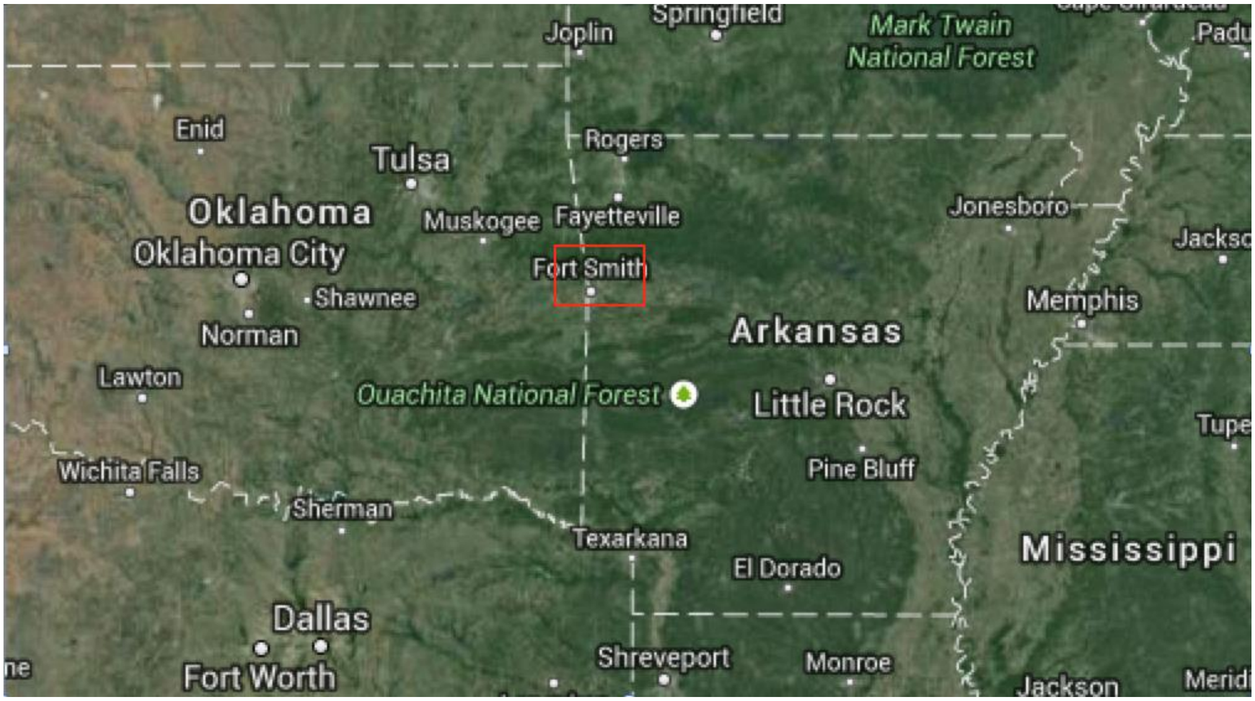


Figure 1. Map view of study area.

The Hunton has produced approximately 93 BCF of gas in the study area. The gas has been produced from the Penters (Sallisaw) Formation and from members of the Chimneyhill Subgroup. The bulk of this production comes from wells located in Sebastian County, near Fort Smith. The most productive well has been the Bertha Williams well located in T8N. R31W. Sec .30. This well has produced approximately 16 BCF of gas. As shown in Figure 14, this is also the area where the Hunton is the thickest. Figure 2 is a map displaying Hunton producing wells.

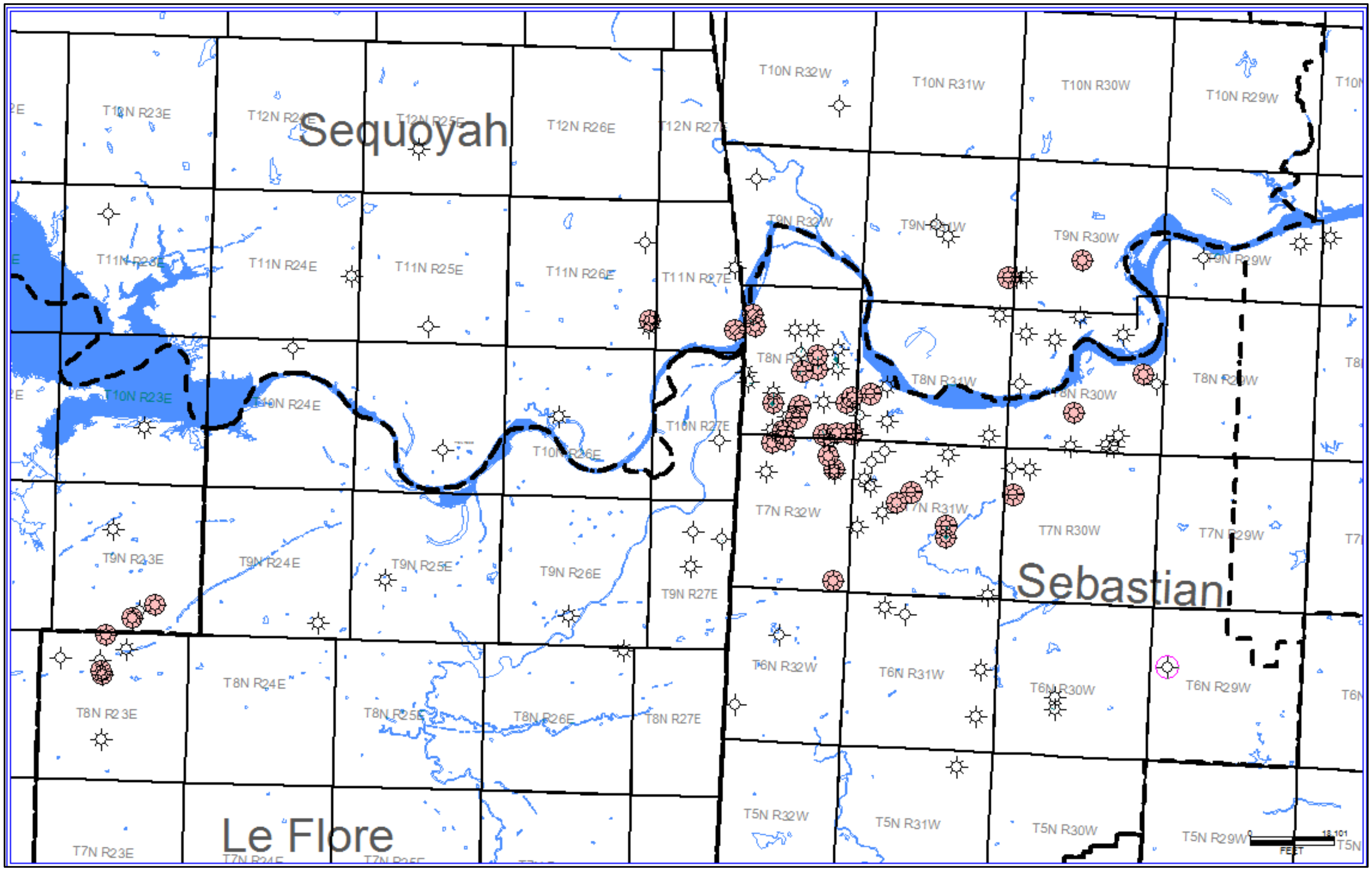


Figure 2. Map view highlighting wells in red that are producing hydrocaborns from the Hunton Group.

Purpose of Investigation

The purpose of this study was to gain a better understanding as to why porosity and permeability is seemingly sporadically present throughout the Hunton Group. Within the study area, porosity is very well developed in some wells and abruptly non-existent in other neighboring wells. Preliminary research suggested that the porosity is directly related to the depositional facies, dolomitization and later diagenetic events. The first goal was to gain a better understanding of this relationship and secondly investigate the origin of the porous dolomite and determine whether the dolomite formed due to hypersaline conditions, deep burial, or the mixing of meteoric water and ocean derived brines.

Methodology

The methods below were undertaken to addresses the target questions. All log correlation and maps were produced using IHS Petra software. Petra is an integrated application with a common database and interface for project and data management; well log analysis, mapping, cross-sections, seismic integration, production and reservoir analysis and 3D visualization. Logs from approximately 560 wells in the study area were loaded into Petra and evaluated; of those wells, 122 were selected based on drilling depths and penetrated formations.

Well log analysis

Wireline logs were evaluated and correlated based on log signatures. These correlations were made through the use of gamma logs and resistivity logs. Density, induction, and photoelectric index (Pe) logs were also used to identify the presence of dolomite in the wells. Dolomite has a reading of about 3 barns/electron on a photoelectric log, whereas limestone has a higher measurement of about 5 barns/electron. Distinguishing the lithology of the producing

Hunton horizons supports the theory that hydrocarbon production is predominately coming from horizons that have undergone at least partial dolomitization.

Regional cross-sections

With the use of the correlated wireline logs, three north to south cross section were constructed through the study area. An east to west cross section was also constructed, spanning the middle of the study area. The cross sections highlight the stratigraphic high in the Kinta Field and also display the overlaying unconformity and the porosity pinch out of the Hunton as it crosses into western Arkansas.

Isopach mapping of the Hunton Group and adjacent formations

Isopach maps were constructed through the use of PETRA. The isopach maps display the thickness variations of the Hunton Group and the adjacent formations. The isopach values were computed by using the tops of the correlated marker beds.

Total production map of Hunton Formation

The production map (Figure 2) shows which wells are producing from the Hunton. Figure 56 displays how many BCF's of gas have been produced from each Hunton well. This map work was also completed using the PETRA software.

Quantification of sidewall core data

A total of twelve sidewalls cores were recovered from the Evans No. 6 well. Two of the cores were of the Woodford Shale and the remaining ten were taken from within the Hunton Group. Weatherford Laboratories in Houston, Texas analyzed the sidewall cores. They were analyzed in relation to porosity, permeability, grain density, and X-ray diffraction. The data was used to make a graph (Figure 40) showing permeability versus porosity. The two samples recovered from the Woodford Shale were crushed and powered. These shale samples were analyzed for: bulk density, grain density, water saturation, hydrocarbon saturation, and porosity. These samples were measured as received and after vacuuming drying at 180 degrees F. This data was also used to make a graph (Figure 43) showing permeability versus gas in place.

Petrographic analysis of thin sections

Ten thin sections were prepared from the sidewall cores taken from the Evans 6 well. The thin sections were analyzed and described in detail. The descriptions focus on the constituents and porosity of the samples. The plates have been stained with Alizarin Red S to help distinguish between calcite and dolomite. Calcite, when stained with Alizarin Red S, turns light red in color. Pore spaces were injected with blue epoxy, therefore the blue colorization is indicative of porosity.

Analysis of cored intervals and samples

Well cores and samples were collected from two different wells within the study area. The Farmers Flag well, located in the Kinta Field, was drilled in the 1974 by Exxon Mobil. The core includes the entire Hunton unit, which is roughly 145 feet thick in this area. The core has been examined and a core log with lithological descriptions has been constructed based on the observations. The Farmers Flag core is stored at the Oklahoma Geological Survey in Norman, Oklahoma. Another Hunton core was studied from the neighboring Bonanza Field in western Arkansas. Shell began developing the field in the 1960's and several cores from the Bonanza Field are stored at the Arkansas Geological Survey in Little Rock, Arkansas. The Shell 1 Western Coal and Mining Co. core and cuttings were studied in detail and a core log was also constructed. This well penetrated the Arbuckle Formation and contains 149 feet of Hunton strata.

GEOLOGIC SETTING

Arkoma Basin

The Arkoma basin is one of seven foreland basins that formed during the Late Paleozoic Ouachita Orogeny and lie along the front of the Ouachita and Appalachian Mountains (Sutherland and Manger, 1979). The structurally complex Arkoma Basin extends approximately 250 miles from its western margin, the Arbuckle Mountains, to the Mississippi Embayment on its eastern margin. It is approximately 20-50 miles across from its northern boundary, the Ozark Uplift and Central Oklahoma Platform, and the Ouachita Fold Belt on its southern margin (Zachry and Sutherland, 1984). The northern part of the province developed in front of the Ouachita Fold. The exposed parts of this fold and thrust belt are the southern most part of the province. The Choctaw fault defines this boundary between the Arkoma Basin and Ouachita orogenic belt. Figure 3 is a map showing the location of the study area and the Arkoma Basin in relation to other hydrocarbon producing basins in the midcontinent. The foreland basins are those that are adjacent to the Ouachita fold belt and include the Arkoma, Marfa, Val Verde, Kerr, Fort Worth, Black Warrior, and not shown in Figure 3, the Appalachian Basin.

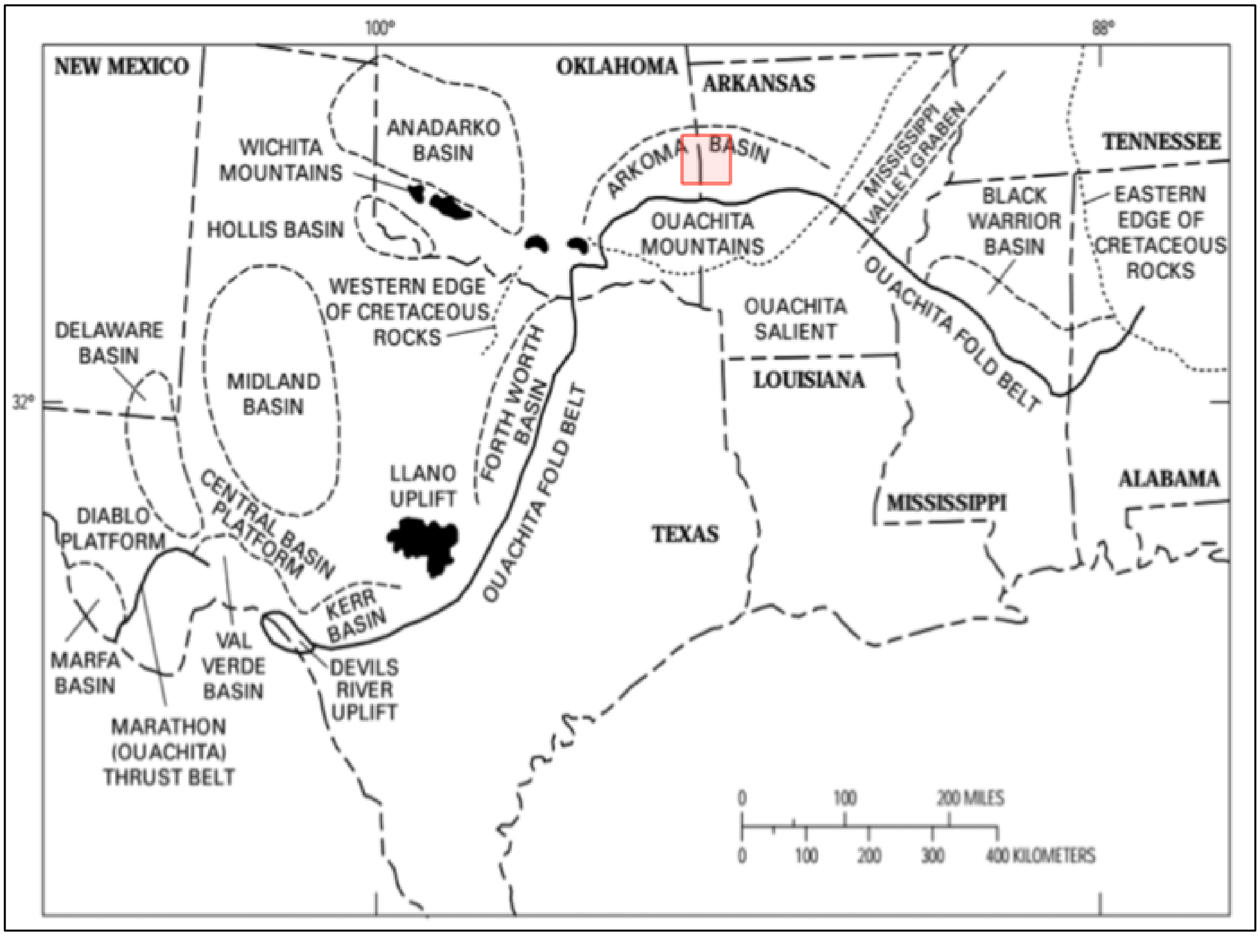


Figure 3. Map showing the location of the study area and the Arkoma Basin in relation to other hydrocarbon producing basins in the midcontinent. Modified from (Denison, 1989).

Sediments in the Arkoma Basin range from 3,000 to 20,000 feet in thickness and consist mainly of pre-Mississippian carbonate shelf deposits, organic bearing Mississippian marine shale and Pennsylvanian fluvial deposits. The majority of this Early and Middle Pennsylvanian section is present in the Arkoma Basin (Perry, 2001).

The Arkoma Basin is dominated by down-to-the-south normal faults that disturb early Pennsylvanian strata and the underlying formations. The Arkoma Basin did not become a foreland basin until the beginning of middle Atokan deposition (Zachry and Sutherland, 1984). Prior to this, sediments were deposited across a tectonically stable shelf that formed the southern boundary of the North American craton. During this time, a broad epicontinental sea covered most of the midcontinent and deposited a blanket of marine carbonates that are interbedded within shales and sandstone (Johnson, 1988). This tectonically stable shelf environment existed for approximately 93% of the Paleozoic time, but the sediments deposited during this time of stability only account for 16% of the total basin fill (Houseknecht, 1987).

During the Devonian or Mississippian, the ocean basin began to close, but deposition along the shelf was not affected until middle of the Pennsylvanian (Sutherland, et al. 1988; Houseknecht, 1987). By middle Atokan time (Middle Pennsylvanian), the ocean closure continued and the northward progression of the subduction zone caused the stable shelf to begin flexing. The stress resulted in the shelf being faulted with large down to the south normal faults that parallel the Ouachita trend. As deformation continued, the shelf began to break up from the south to north and formed step like series of fault blocks, (Buchanan and Johnson, 1968; Zachry, 1983), which resemble half grabens in cross-sectional view (Houseknecht, 1987). These growth faults significantly contributed to the overall thickness of the middle Atoka clastic wedge from north to south; this is due to the accumulation of submarine fan sentiments on their southern down thrown sides (Zachry and Sutherland, 1984).

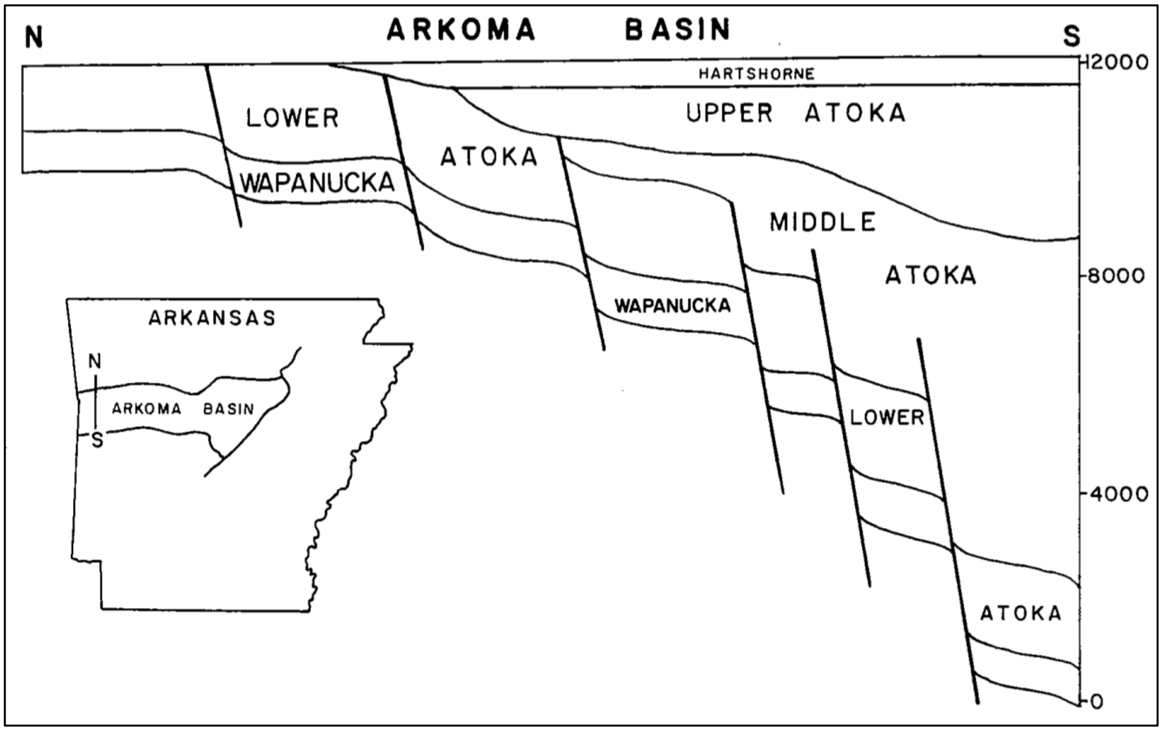
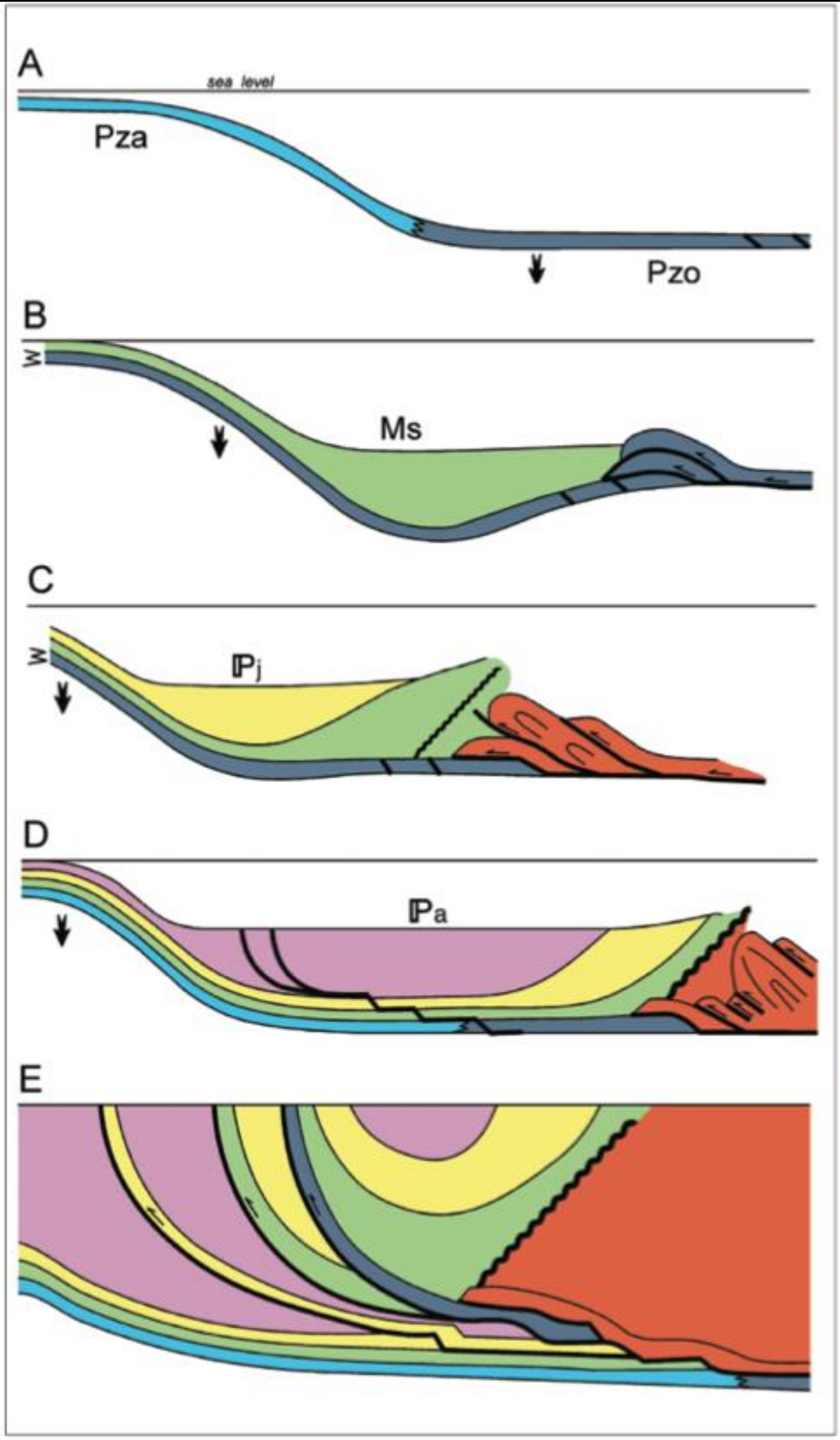


Figure 4. North to south section across the Arkoma basin illustrating pattern of growth faulting that controlled sedimentation during accumulation (Zachary and Southerland, 1984).



During the Cambrian-Devonian the Arbuckle strata (Pza) was deposited on a northern shelf as the same time as the Ouachita strata in the southern basin.

Subsidence of Stanley (Ms) foreland basin in response to thrusting and tectonic loading.

Subsidence of Jackfork (Pj) in response to continued tectonic activity.

Subsidence of Atoka (Pa) foreland basin, in response to the continuation of thrusting and tectonic loading. The wedge zone remains below sea level,. Thick black lines indicate the location of subsequent thrust faults.

Severe telescoping of all but the northern part of the Arkoma basin to form Ouachita tectonic belt.

Figure 5. North to south cross-sections showing the development of the Ouachita tectonic belt and Arkoma basin (Suneson, 2013).

LITHOSTRATIGRAPHY OF THE HUNTON GROUP AND ADJACENT FORMATIONS

The Devonian was a time of marine carbonate deposition in the midcontinent of the US. During this time shallow seas covered the midcontinent and layers of limestones and dolomites were deposited in a ramp setting. The overall slope was generally towards the south with the deepest water in the Oklahoma aulacogen region (Fritz and Medlock, 1994).

The Hunton Group is composed of sequences of limestone, dolomite and calcareous shale. Figure 6 is a map showing the distribution and thickness of Silurian Strata across North America. The Hunton Group is divided into different subgroups and formations, based on the various facies. Deposition of the Hunton Group began during late Ordovician time and continued throughout most of the Devonian.

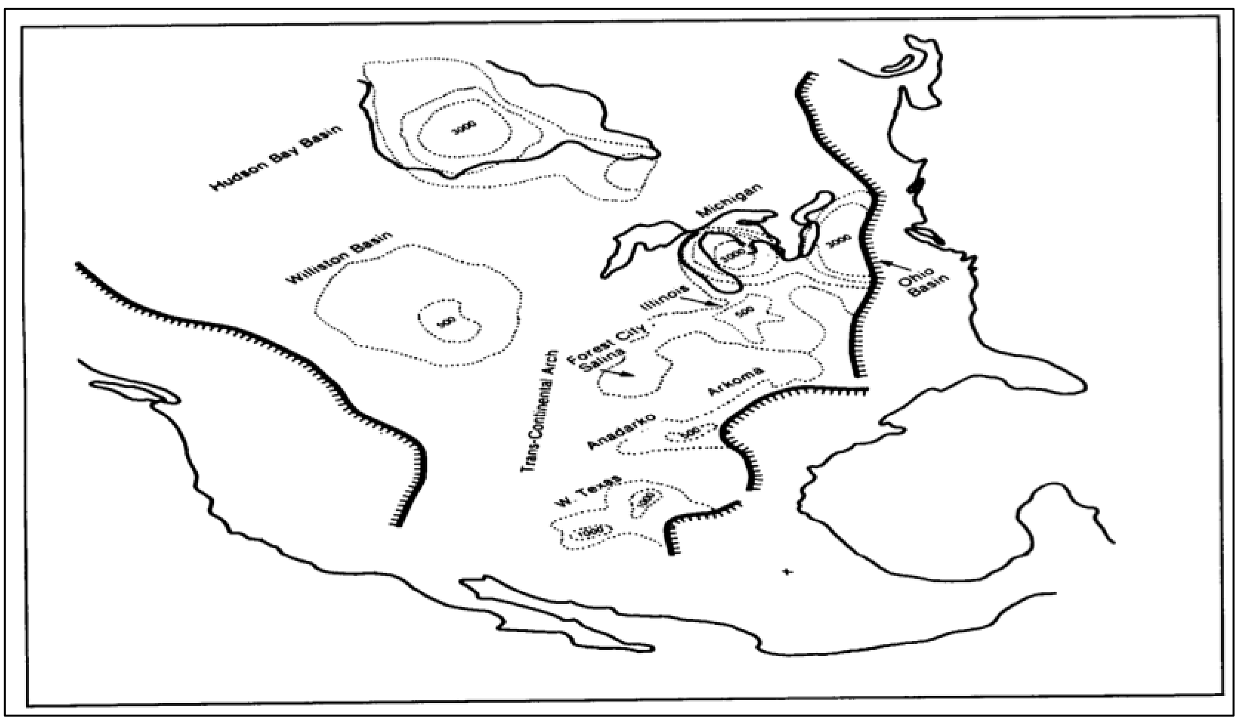


Figure 6. Map showing the distribution and thickness of Silurian Strata across North America (Fritz and Medlock, 1994).

The Ordovician Keel Formation is the basal unit of the Hunton Group; it is part of the Chimneyhill Subgroup, which also includes the Silurian aged Cochran and Clarita Formations. These formations are composed of dolomitic limestones and dolomites. The Chimneyhill Group is comprised of clean skeletal limestones and dolomites. Overlying the Chimneyhill Group are the slightly argillaceous and silty limestones and dolomites of the Silurian Henryhouse Formation and Devonian Hargan Formations. (Gaswirth and Higley 2013.) The Henryhouse reservoirs are characterized as a dolomitized intertidal facies. The Devonian Frisco Limestone in central and southern Oklahoma overlies the Henryhouse Formation. The Frisco consist of grainstones and skeletal packstones; that are comprised of brachiopods, pelmatozoans and corals (Morgan and Schenider, 1981).

The Hunton Group conformably overlies the Sylvan Shale and is unconformably overlain by the Chattanooga (Woodford) Shale, Figure 7. Due to this unconformity, portions of the Hunton Group have been eroded away in the study area. The thickness of the Hunton varies greatly and the unit is nonexistent in some areas. The overlying unconformity is due to a major uplift and erosion during Early to Late Devonian time. During this time most of the Hargan-Bois d' Arc and Henryhouse Formations were stripped away from western Arkansas and eastern Oklahoma. In producing reservoirs, the dissolution and erosion of the exposed Hunton are key components of porosity development. Dolomitization, fracturing, and dissolution play an important role in porosity development. The majority of conventional reservoirs are in rocks that have undergone dissolution, or dolomitization.

Later in the Devonian, a marine transgression deposited the Woodford Shale over the exposed Hunton Group. The Woodford Shale serves as a lithological seal and is also the hydrocarbon source rock for the Hunton. The lab analyses of the two Woodford Shale sidewall cores, from the Evans No. 6 well, did indicate the presence of gas; 51% of PV. Oil saturation was not detected in the samples. The Henryhouse and Chimneyhill appear to be the only members of the Hunton Group still present in the Evans No. 6 well. The younger members were eroded away during the time of Devonian exposure. Across much of Oklahoma and Arkansas, significant portions of the Hunton were removed during the pre-Woodford uplift.

Figure 7 is a stratigraphic column that shows the age and correlation of the different Hunton formations and members. It is important to note the variations in the names of the formations, between Arkansas and Oklahoma. These are also indicated in the descriptive section of the individual formations.

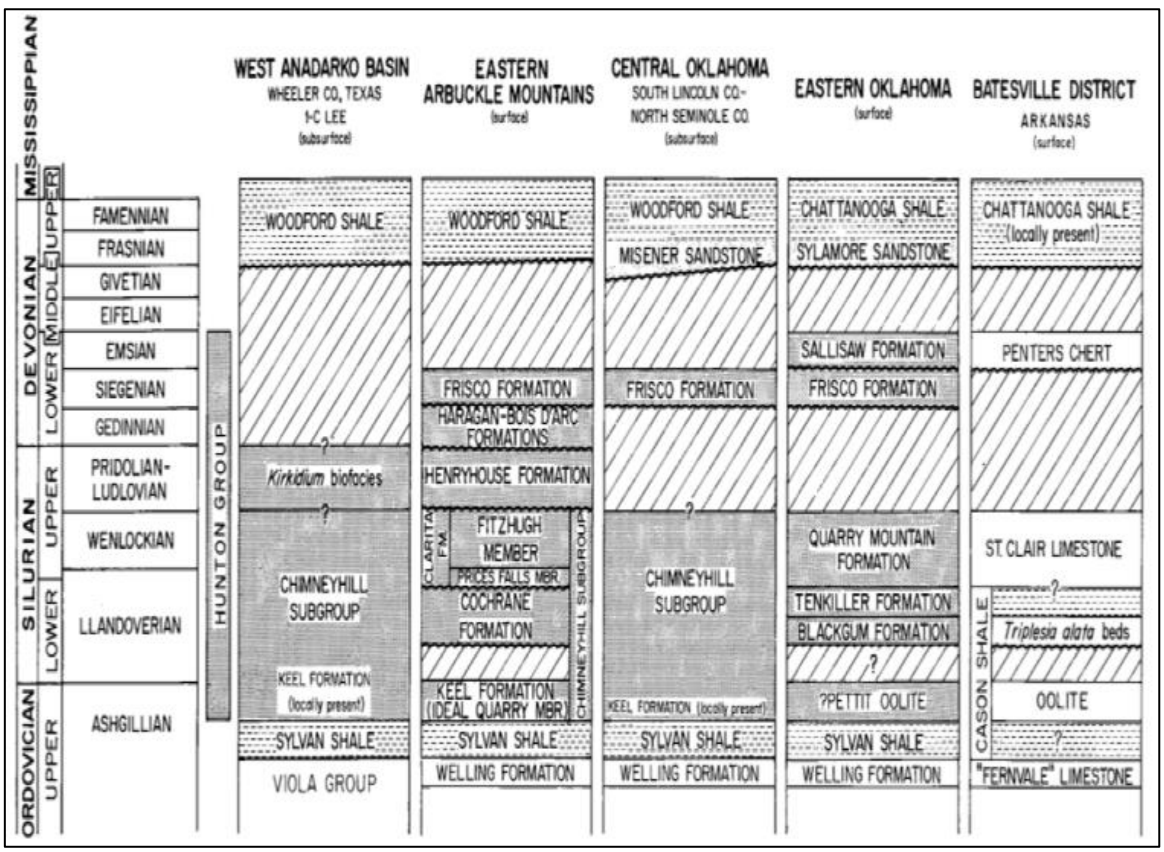


Figure 7. Stratigraphic chart showing inferred relationship of late Ordovician to Early Mississippian Strata (Amsden, 1980).

Formations

Sylvan (Cason) Shale

The Late Ordovician shale at the base of the Hunton Group is referred to as the Cason Shale in Arkansas. In Oklahoma it is known as the Sylvan Shale. Jenkins (1970) collected chitinozoans of late Ordovician age from the entire Sylvan Formation. Amsden described the Sylvan as having an upper and lower part. The upper portion consists of a greenish-gray dolomitic shale that grades into a argillaceous dolomite, while the lower part is often comprised of dark gray noncalcareous shale. This two-part division is clearly displayed in the Shell 1 Western Coal and Mining Co well (Figure x). The core includes an interval 4 feet thick of Sylvan Shale, with the upper 2 feet consisting of a greenish gray argillaceous dolomite, underlain by 2 feet of dark gray dolomitic shale. In some areas the Sylvan grades into a strongly calcareous shale and argillaceous limestone, this can make log correlation exceptionally challenging (Rottmann, 2000). The Sylvan Shale is less than 50 feet thick in the eastern part of the Arkoma basin. Near the Arkansas Oklahoma border, the Sylvan is about 25 feet thick and it begins to thicken towards the southwest. The Sylvan reaches a thickness greater than 300 feet in the western part of the Arbuckle Mountains. Thin areas of Sylvan are often indicators of structural uplift (Amsden, 1980).

Chimneyhill Subgroup

The Chimneyhill subgroup contains sequences of late Ordovician early late Silurian limestones. Three formations make up the subgroup and they include, a basal Keel Formation, middle Cochran Formation, and an upper Clarinet Formation. In outcrops the subgroups are readily distinguished from the underlying Sylvan Shale and overlying marlstones of the Henryhouse Formation. However, through much of the subsurface, these middle marlstone beds of the Hunton disappear, either by changes in facies, or due to erosional events (Amsden, 1975). In these areas, early Devonian organo-detrital limestones overlie the Chimneyhill subgroups. These similar deposits caused the Chimneyhill to lose its unique lithological identity and they can only be identified through fossil records. Identifying these subgroups in the study area is exceedingly difficult. On well logs from the Bonanza and Kinta field, it is not uncommon to see the Chimneyhill subgroups simply identified as lower Hunton. The Chimneyhill subgroups are described as follows, but note they are not depicted on the accompanying well logs.

Keel Formation (Pettit Oollite)

The Keel Formation does not exceed a thickness of 15 feet, and occurs irregularly due to an erosional unconformity that followed after deposition. The Keel is a low magnesium oolite. The ooliths are spiracle and have a radial or concentric internal structure (Amsden, 1960.) Most of the ooliths have an organic nucleus and in areas the Keel grades into an organo-detrital limestone in which the fossils were lightly coated by precipitated carbonate material (Amsden, 1980). Amsden points out that ooliths are not unique to only the Keel Formation, however the ooliths are usually distinctive. The Keel is nearly impossible to identify on geophysical logs alone, cores or cuttings are needed to positively determine its presence.

Cochrane

The Cochrane Formation is described as a low magnesium, skeletal limestone with abundant fauna including brachiopods, trilobites, bryozoans, mollusks, and corals, (Amsden 1971). Amsden states that the Cochran formation ranges up to 60 feet in thickness but on average is about 20 feet thick. The most distinguishing characteristics of the Cochran is the presence of chert and irregular bedding in outcrops.

Clarita (St. Clair)

The Clarita is divided into two separate members the lower being the Price Falls Member and an upper Fitzhugh Member. The distinction between these two members is clear. The Price Falls Member consists of a low calcium shale. The Fitzhugh Member consist of a low magnesium oragan-detrail limestone that is thinly and evenly bedded (Amsden, 160). Articulated brachiopod shells are common which is an indication that transport and energy has been minimal. The fauna present likely represents faunal assemblages. Amsden (1980) divided the Fitzhugh Member into three separate lithofacies-biofacies. (1) crinoidal sparite, (2) arthropod micrite, (3) ostracode silty marlstone. He described each one of these facies as having distinctive features and mentioned that they probably grade into one another locally. He also indicated these unique biofacies are indicative of distinctive environments. Geophysical log signatures of the Clarita Formation are distinctive and maintain uniformity over much of the southern and central part of Oklahoma. However, in far eastern Oklahoma and western Arkansas, (the study area) the correlation of the Clarita is extremely difficult, if not impossible.

Henryhouse Formation

The Henryhouse Formation represents the youngest of the Silurian deposits. The Henryhouse primarily is a marlstone with a mud-supported matrix. On wire line logs, the contact between the Henryhouse and Chimneyhill Formation is one of the more easily recognized contacts in the Hunton Group. The Henryhouse Marlstone lies on top of the organo-detrital limestone of the Clarita Formation. Gamma ray log signatures of the Henryhouse are much higher than that of the Clarita. The contact also displays an increase in resistivity from the Henryhouse to Clarita Formation.

Hargan (Bois d’ Arc Formation)

The lithologies of the Devonian aged Hargan Formation is very similar to that of the underlying Henryhouse Formation, and are often found to be treated as a single unit in some reports. A mud-supported fabric characterizes the Hargan marlstone, with fossils scattered in varying degrees of intensity (Amsden, 1980). The difference between the two formations is the Hargan contains a prolific invertebrate fauna of distinct Helderbergian age. This difference in faunal age is the only available way of distinguishing the two formations, as they are nearly identical lithologically.

Frisco

Based on the study and brachiopods Amsden assigned the Frisco Formation to the early-middle Devonian age. The Frisco is a light gray to pinkish gray organo-detrital grain -supported limestone. It contains a wide variety of shell debris that appears to have been fragmented and disarticulated before deposition. The Frisco is a low magnesium limestone averaging only 1% of magnesium carbonate. This magnesium content is important to note, because dolomite occurs both above and below this limestone and the dolomitization did not have an affect on the Frisco. The insoluble residue are also low at 2-3 % (Amsden, 1980). Frisco strata show little variation in lithostratigraphic and biostratigraphic character.

Penters (Sallisaw)

Amsden (1980) described the Sallisaw (Penters) as an arenaceous, dolomitic limestone with traces of glauconite and contain an average of 9.5% quartz detritus. The quartz that makes up the insoluble detritus is in the form of angular to sub-angular grains, ranging of 0.15- 2.2 mm in diameter. Nodules and lenses of chert are often present in the Sallisaw, and the dolomitic limestone may grade into a bedded arenaceous chert. The dolomite content varies, ranging from less than 1 % to 25% magnesium carbonate ($MgCo_3$), with the average being about 11% $MgCo_3$.

Chattanooga (Woodford) Shale

The Chattanooga Shale is a Late Devonian to Early Mississippian age. It is a black, silty shale that is rich organics and it commonly contains chert. In Oklahoma, the Chattanooga Shale is commonly referred to as the Woodford Shale. In some locations the Chattanooga contains a basal dolomitic sandstone or siltstone lithofacies referred to as the Sylamore sandstone. Local thickness variations appear to be correlated to variations in the thickness of the underlying Hunton, with the Woodford filling depressions of the old pre- Woodford surface (Amsden, 1980).

DEPOSITIONAL FACIES AND ENVIRONMENTS

The lithofacies are classified according to Dunham's organizational chart. Mud-supported rocks are more prevalent than grain-supported rocks. The Henryhouse to Bois d'Arc Formation are typically mud-supported. However, the Chimneyhill Subgroup and the Frisco Formation tend to have more grain-supported textures. Throughout the various formations, burrows and bioturbation are the most commonly seen depositional structures. Ripple marks and cross bedding are common in the oolitic grainstones and packstones (Fritz and Medlock, 1994).

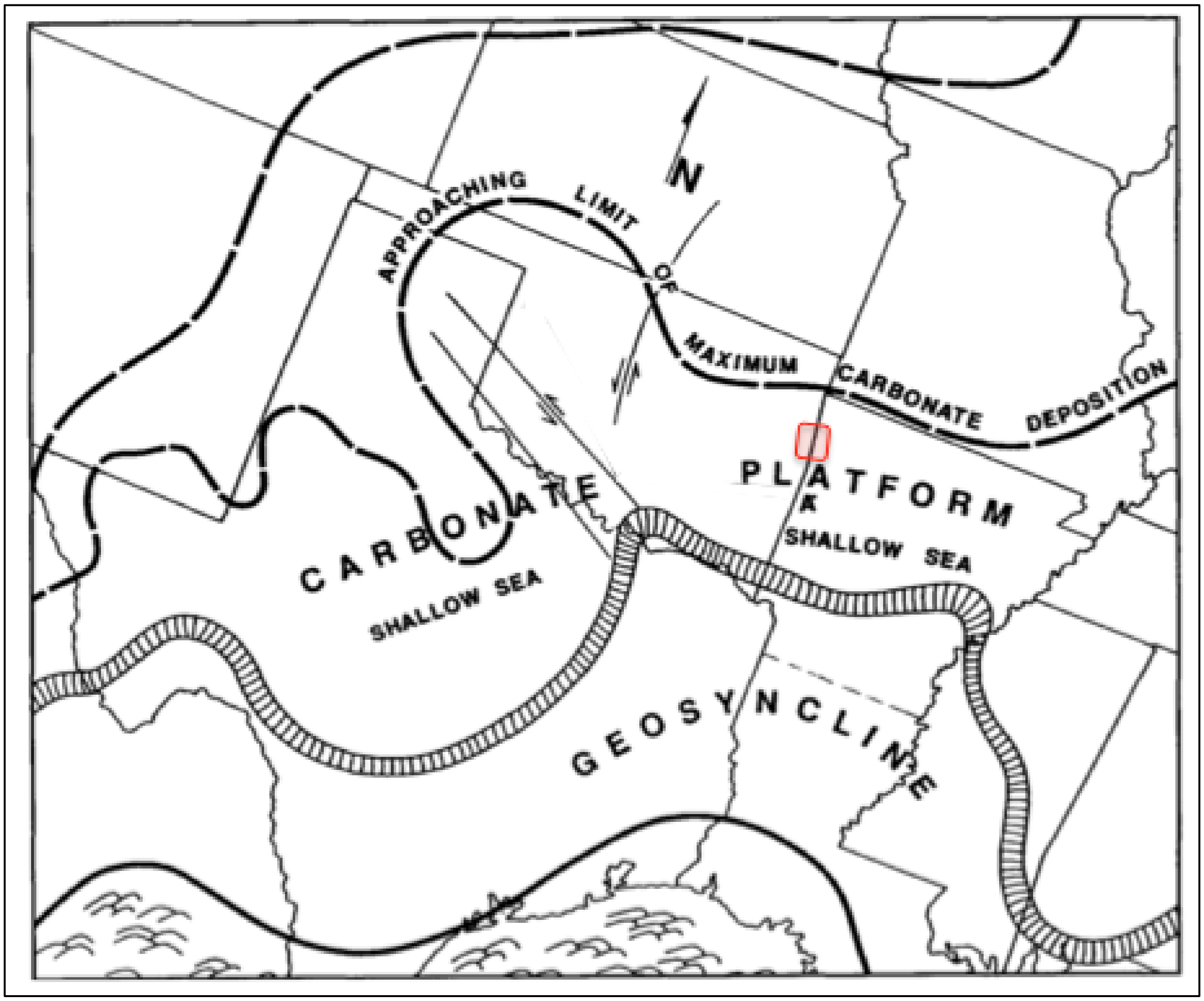


Figure 8. Depositional setting during Hunton time in the Midcontinent, study area highlighted in red (modified from Fritz and Medlock, 1994).

Facies

The midcontinent region remained stable during the Silurian (Adler, 1971). Due to the stable tonic conditions, the Henryhouse Formation was deposited over much of Oklahoma without any significant unconformities (Shannon, 1962). Figure 8 is a diagram showing the depositional setting during Hunton time in the Midcontinent. The Henryhouse Formation is composed of three separate depositional facies, which include: subtitle, intertidal, and supratitle. Figure 9 is a Schematic diagram (Al-Shaieb, 1993) that shows the generalized depositional environments and the various facies. The Henryhouse model is used to illustrate facies that are equivalent to all pre-Frisco Hunton units (Al-Shaieb and others 2000).

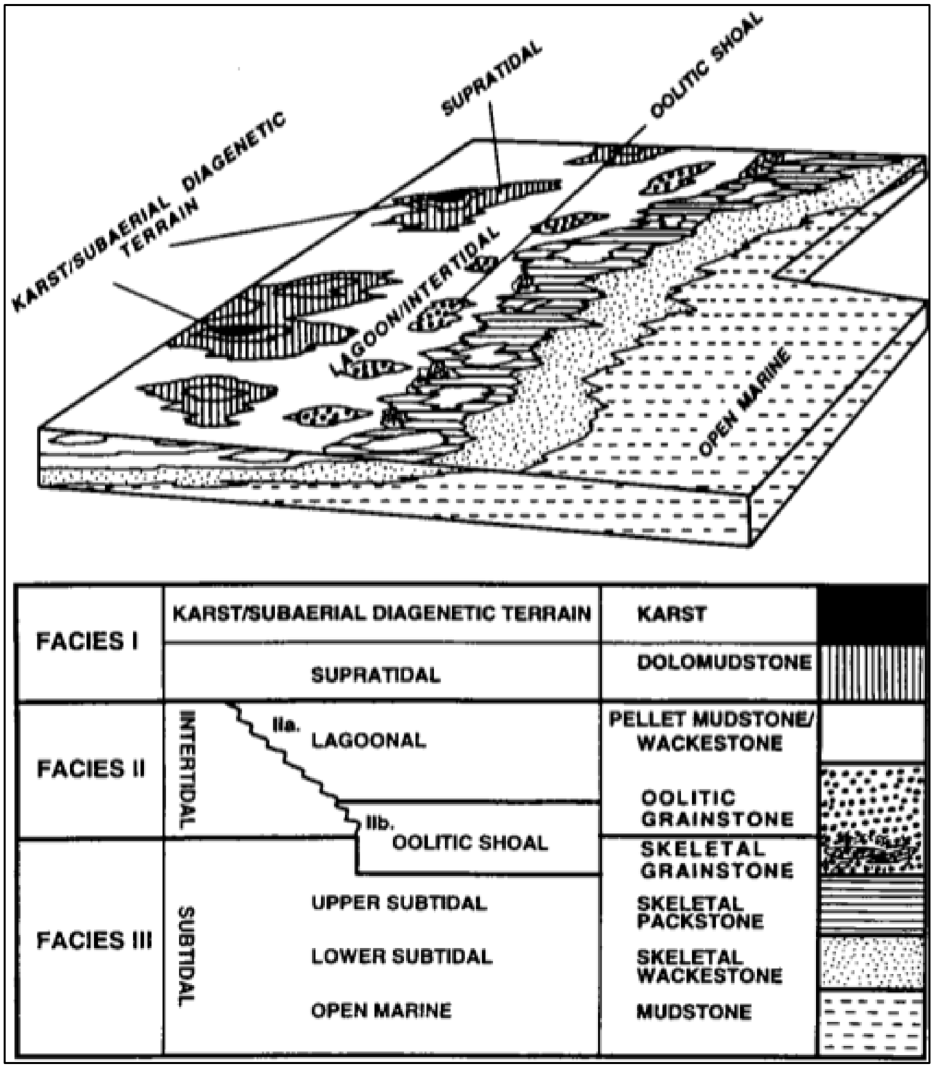


Figure 9. Schematic diagram showing generalized depositional environments and the various facies in the Hunton Group (Al-Shaieb, 1993).

The facies were deposited in a shallowing upward cycle and formed a series of progradational and aggradation sequences. The sequences moved southward across the carbonate ramp, into the deeper part of the basin (Fritz and Medlock, 1994). Extensive migration of the facies, due to the transgression and regression, has produced unique log signatures across large portions of the basin. Figure 10 is a depositional model showing the details of this progradation and aggradation.

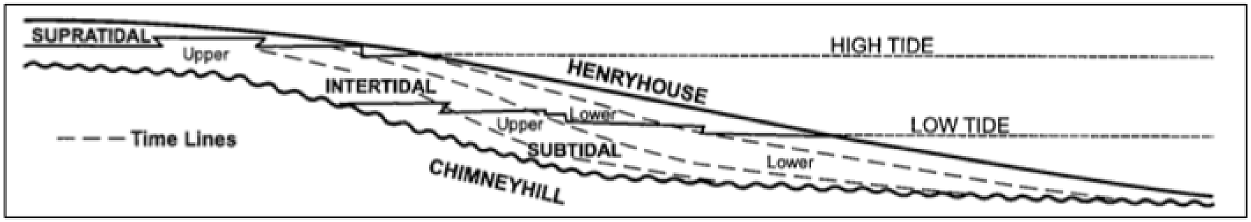


Figure 10. Depositional model showing details of progradation and aggradation (Fritz and Medlock, 1994).

Facies I

The sediments of facies I were deposited on a supratidal flat near mean high tide. Predominant features in this facies include: cryptal algal fabrics and fenestral fabrics. The facies tend to lack fossils and burrowing. Silica nodules, silt- sized quartz grains, interclasts, and peloids, may be present in the low porosity dolomudstones. Facies I indicates a shallow restricted environment(Al-Shaieb, 2000).

Facies II

The sediments of Facies II were deposited in a shallow restricted subtitle to upper intertidal environment. Burrowing features are distinct characteristics of this facies. Rocks are dominantly dolo-wackestones and are completely dolomitized with high amounts of porosity. Fossil types and percentages can only be estimated, due to the dissolution of the original fossils and fragments. Molds and scattered remaining grains indicate the crinoids were common. Vertical burrows and crinoid fragments suggest shallowing waters and an increase of energy (Al-Shaieb, Puckette, and Blubaugh, 2000).

Facies III

The sediments of Facies III were deposited in a subtitle environment. The sediments are commonly dark silty dolomitic mudstones and wackstones. The facies can be featureless or contain burrows, nodular bedding, or even storm surge deposits. The fossils found in this facies include brachiopods, trilobites, ostracods, bryozoans and echinoderms. The more diversity in the fauna indicates a shallow open water environment with little energy (Al-Shaieb, 1993). Figure 11 illustrates the vertical facies sequence, showing sedimentological, faunal, and mineralogical features that are equivalent to all pre-Frisco Hunton units.

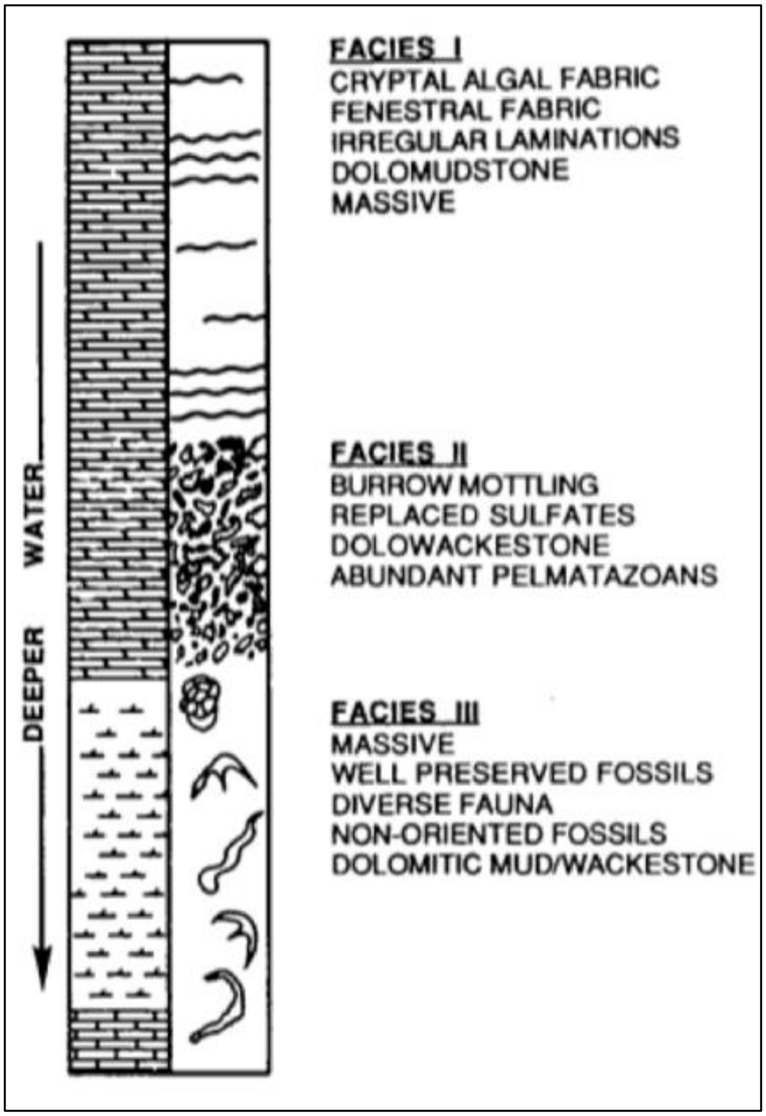


Figure 11. Typical sequence showing sedimentological, faunal, and mineralogical features of the Henryhouse Formation and other pre-Frisco Hunton units (Al-Shaieb, 1993).

<u>Dolomitization</u>

Productive reservoir rocks of the Henryhouse Formation and Chimneyhill subgroup are predominantly due to dolomitization of limestone. Dolomite is a rhombohedral, double Ca, Mg carbonate. The chemical formula of dolomite is $CaMg\ (CO_3)_2$. Pure Dolomite contains: 54.35% $CaCO_3$ and 45.65% $MgCO_3$. Dolomite is a very challenging mineral to form due to the exact arrangement of calcium and magnesium required for formation. Dolomite consists of alternating sheets of calcium atoms and sheets of magnesium atoms. These ions are not easily segregated due to their similar chemical properties. Dolomite can only be formed when the $\frac{Mg^{2+}}{Ca^{2+}}$ ratio is greater than 5:1 to 10:1. This minimum ratio yields poorly ordered layering of the calcium and magnesium sheets (Folk, 1975). The crystal lattice structure of dolomite is closely related to that of calcite. The overall calcite structure is retained while Mg atoms substitute Ca atoms every other cation layer. The Mg cation has an atomic radius of .86 Å. This radius is much smaller than that of the Ca atom, .99 Å. This difference in atom size also creates a disorder of the crystal lattice structure ase well as a difference between the Ca-O bond length and the Mg-O bond length. The bond formed between Ca-O is 2.38 Å in length and 2.08 Å for Mg-O. Due to this difference in bond lengths, all CO_3 groups in every layer are rotated around the three-fold axis relative to their position in calcite (Reeder and Wenk, 1983).

Silurian dolomites were in place before the Early Devonian. This is implied by the fact that the low magnesium limestone of the Frisco Formation did not fully participate in the dolomitization (Amsden, 1980). Three separate stages of dolomitization have been documented in Silurian Hunton rock. These include:

1. Penecontemporaneous hypersaline dolomite, formed seaward of the intertidal zone (Amsden, 1975).
2. Marine and freshwater mixed dolomite (Al-Shaieb, Puckette, and Blubaugh, 1993).
3. Deep burial or thermal dolomite (Al-Shaieb, Puckette, and Blubaugh, 1993).

Amsden admits (1980) that these models do encounter difficulties, especially with respect to the extraction of magnesium from open seawater. He described the origin of these dolomites as being a difficult and perhaps even unsolvable problem.

Hypersaline Dolomite

The hypersaline dolomite formed in the supertitle area of the inner ramp shelf area. Anhydride and other evaporites suggest that evaporation of the super tidal area was capable forming of hypersaline brines. Poorly formed rhombohedra and cloudy dolomite crystals are characteristics of dolomites that form in hypersaline conditions (Al-Shaieb, 2000). Due to the precipitation of calcium sulfate ($\mathrm{CaSO_4}$), $\frac{Mg^{2+}}{Ca^{2+}}$ ratios increased. This plays a key role in formation of dolomite. Fluids with high $\frac{Mg^{2+}}{Ca^{2+}}$ ratios likely enhanced dolomitization in the intertidal – shallow-subtidal facies as shown in Figure 22 (Al-Shaieb, 2000). Hypersaline dolomite begins crystalizing only when $\frac{Mg^{2+}}{Ca^{2+}}$ ratios exceeds 5:1 to 10:1. Carbonates formed below this ratio crystalize into the easier formed aragonite or magnesian-calcite. Precipitation is rapid in hypersaline environments and often other foreign ions are present. These ions inhibit the precise ordering of calcite and magnesium sheets required for dolomite formation. This rapid rate of crystallization produces poorly formed rhombohedra crystals (Folk, 1975).

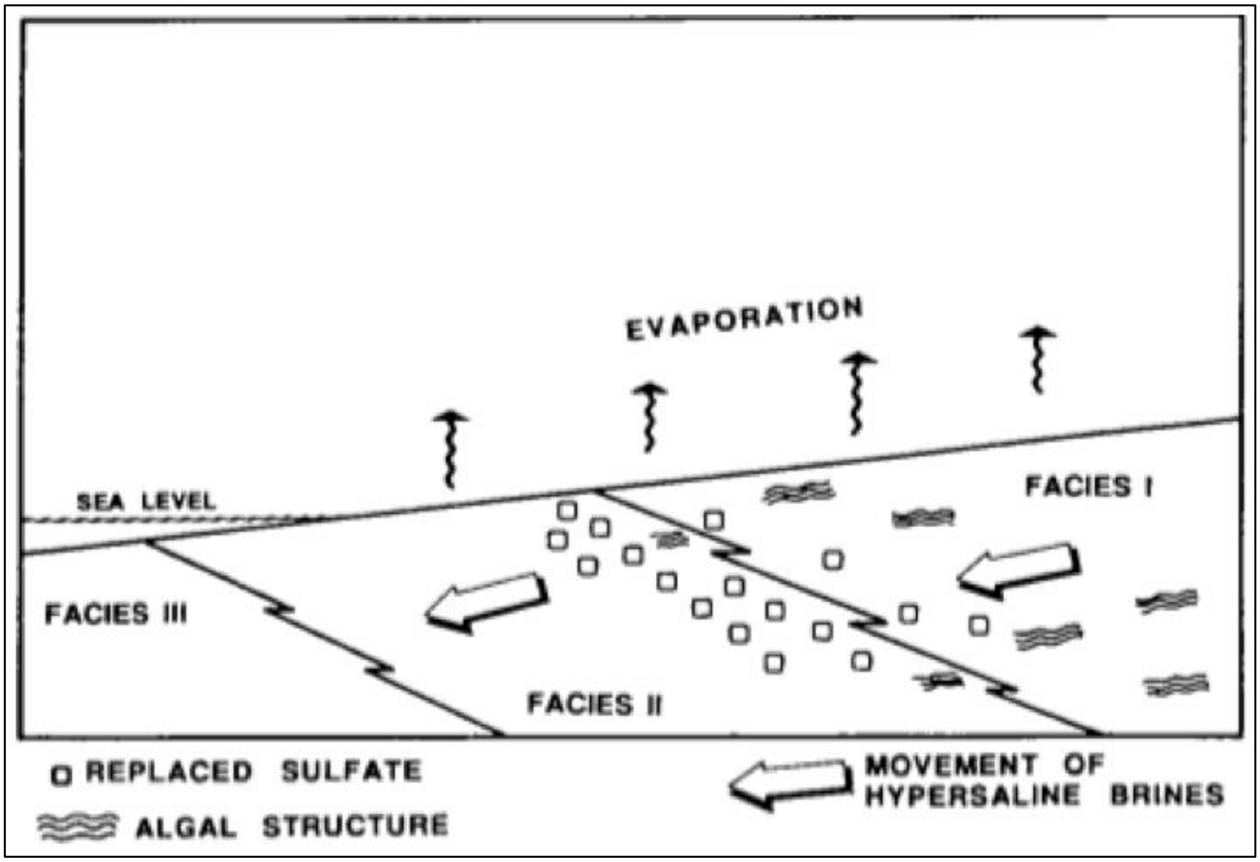


Figure 12. Schematic diagram illustrating the regressive movement of hypersaline brines and their role in dolomitizing Hunton carbonates (Al-Shaieb, Puckette, and Blubaugh, 1993).

Mixed water dolomite

Mixed water dolomites form due to the migration of meteoric water mixing with ocean derived brines. Dropping sea levels and a basinward shift of the shoreline, would have allowed the meteoric waters to migrate through the sediments. A mixed water mechanism yields exceedingly clean overgrowths of dolomite and there is a uniform distribution of dolomite across the facies. The phreatic conditions lack foreign ions and allow for a slower crystallization rate. This longer period allows for the formation of euhedral dolomite and calcite rhombs as shown in Figure 13, B and C. Dolomite can form in these mixed water conditions with $\frac{Mg^{2+}}{Ca^{2+}}$ ratios as low as 1:1, assuming the crystallization rate is slow enough. Faster crystallization requires a greater

$\frac{Mg^{2+}}{Ca^{2+}}$ ratios. Cathodoluminescence of dolomite samples throughout the Henryhouse Formation is regionally similar, which suggest a common digenetic history (Choquette and Steinen, 1980). After the deposition of the Hunton Group, a system of recharge may have been responsible for the additional mixed-water dolomite in the Hunton Group. Freshwater could have migrated towards the basin and mixed with intertidal seawater that had a higher magnesium concentration. The mixing of freshwater and seawater is considered the most likely mechanism for areas of regional dolomitization in the Chimneyhill subgroup and Henryhouse Formation (Al-Shaieb, 2000).

Saddle Dolomite

Deep burial dolomite, or also known as saddle dolomite, is found in secondary voids and fractures in various portions of the Hunton Formation. The curved and distorted crystal lattice structure of saddle dolomite, as shown in Figure 13, D, is indicative of temperatures in excess of 80° C. This suggests a deep burial or a hydrothermal origin at shallower depths (Al-Shaieb, Puckette, and Blubaugh, 1993).

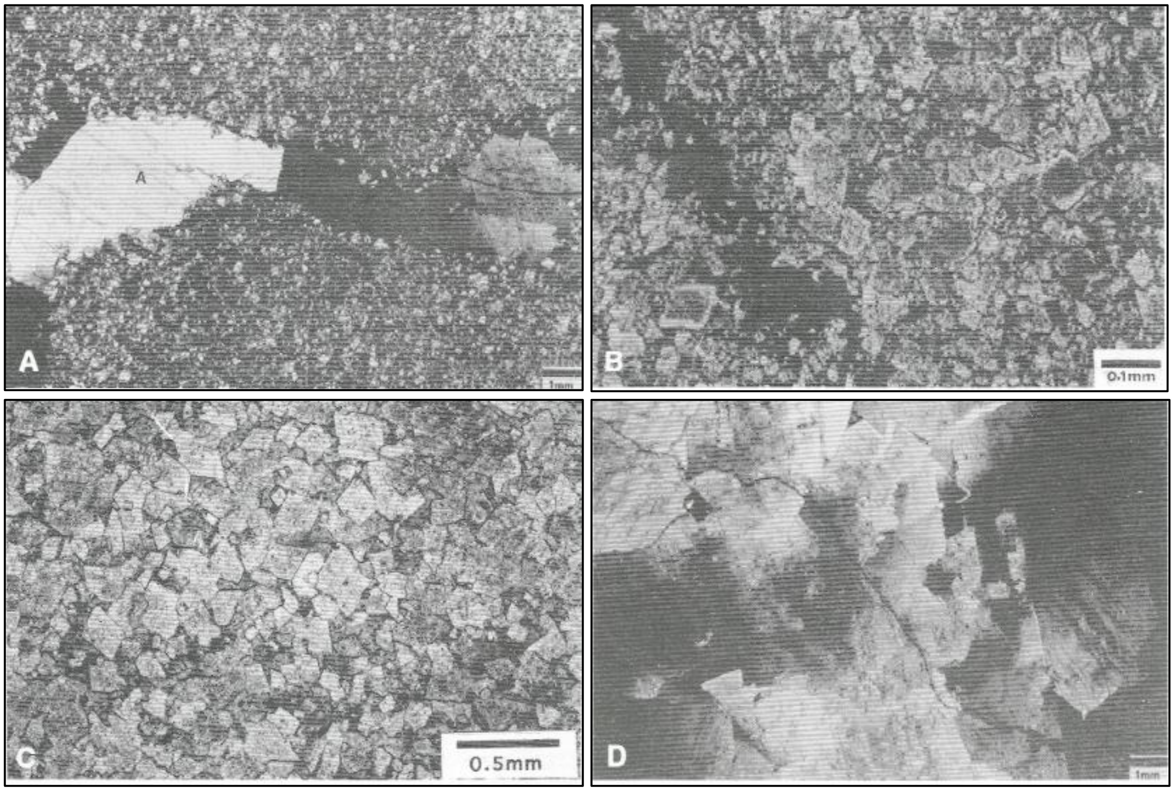


Figure 13 Photomicrographs illustrating the different types of dolomite found in the Hunton Group. (A) Dolomite formed in hypersaline conditions with cloudy and poorly formed rhombs. Porous vuggs are in-filled with anhydrite cement. (B, C) Dolomites formed by the mixed water mechanism. Euhdral rhombohedra with dark centers are characteristics of mixed water dolomites. Also, note the lack of anhydrite cement and other evaporites. (D) Curved saddle dolomite formed due to deep burial or hydrothermal conditions (Al-Shaieb, Puckette, and Blubaugh, 1993).

Porosity

Four separate types of porosity have been recorded within the Hunton Group. These include vuggy, moldic, intercrystalline, and fracture. Moldic and intercrystalline are responsible for the majority of the porosity found in the Hunton Group. Moldic porosity is created by the dissolution of fossil fragments; in this case, the fossil fragments are mainly crinoid and mollusk pieces. These molds were often partially infilled with saddle dolomite or calcite crystals, during digenesis. Intercrystalline pore space is due to the dissolution of non-dolomitized calcite matrix. Intercrystalline porosity likely evolved between larger rhombic crystals in mixed water dolomites. Often calcite cement fills these intercrystalline pore spaces, reducing porosity and permeability.

The relationship between porosity and dolomitization is very apparent, but depositional facies also play an important role in porosity. Porosity tends to be better developed in the intertidal facies of Facies II, most notably in the bioturbated and burrowed wackestones (Al-Shaieb, Puckette, and Blubaugh, 1993). Burrowing and the common pelmatozoan fragments are the two main contributing factors to porosity. The burrowing distributes finer grained particles, which ultimately allows low pH fluids to move through the rock matrix and dissolve any non-dolomitized matrix. Burrowing is responsible for the inconsistent distribution of areas with higher porosity (Al-Shaieb, Puckette, and Blubaugh, 1993). This random distribution was also observed in cores and thin sections by Al-Shaieb.

Moldic porosity is more prevalent in grain rich rocks. Facies II and III are fossiliferous, but facies II, when highly dolomitized, have developed much more moldic porosity than that found in facies III. The porosity in oolitic grainstones is primarily interooid. Porosity in non-dolomitized oolitic rocks is less developed due to the earlier cementation of sparry calcite. In less burrowed zones, the dissolution of fossil fragments was the most crucial factor in developing moldic and vuggy porosity (Al-Shaieb, Puckette, and Blubaugh, 1993).

SUCCESSION OF THE HUNTON GROUP AND ADJACENT FORMATIONS IN THE KINTA AND BONANZA FIELD

Throughout the study area, the Chattanooga (Woodford) Shale, Hunton Group, and the Sylvan (Cason) Shale have created a distinct shale-carbonate-shale sequence in the subsurface.

In the eastern Arkoma Basin, from about Range 12 east, eastward into Arkansas, the Hunton Group (Chimneyhill) conformably overlies the Sylvan (Cason) Shale and is unconformably overlain by either the lower Devonian Frisco formation, by the lower Devonian Sallisaw Formation, or only by the Upper Devonian Chattanooga (Woodford) Shale. The variation in Hunton thickness is due to two major uplifts during and after the deposition of the Hunton Group. This Early to Late Devonian time of exposure significantly altered the Hunton paleotopographic surface and created regional unconformities.

Chattanooga (Woodford) Shale

The Chattanooga (Woodford) Shale or its basal member, the Sylamore Sandstone, overlies the Hunton Group. The boundary between the Chattanooga Shale and the underlying Hunton Group is known to be diachronous (Freeman and Schumacher, 1969). The Chattanooga is present in all wells throughout the study area, but there are variations in the thickness. The Chattanooga (Woodford) Shale is an important component in reservoir development in the fact that is serves as both a lithological seal and is the hydrocarbon source rock, for the Hunton Group. The shale works as a seal in two basic ways: 1) as a sealing boundary against a porous and impermeable stratigraphic units it is been faulted adjacent to the Chattanooga, and 2) as a stratigraphic boundary in which the shale forms an overlying barrier to an underlying porous and impermeable strata (Rottmann, 2000). As previously mentioned, local thickness variations appear to be related to variations in the thickness of the underlying Hunton, with the shale filling depressions of the old pre- Woodford surface. Chattanooga thickness values in the study area range from 1.5 feet to 125 feet. Figure 13 is an isopach map of the Chattanooga (Woodford).

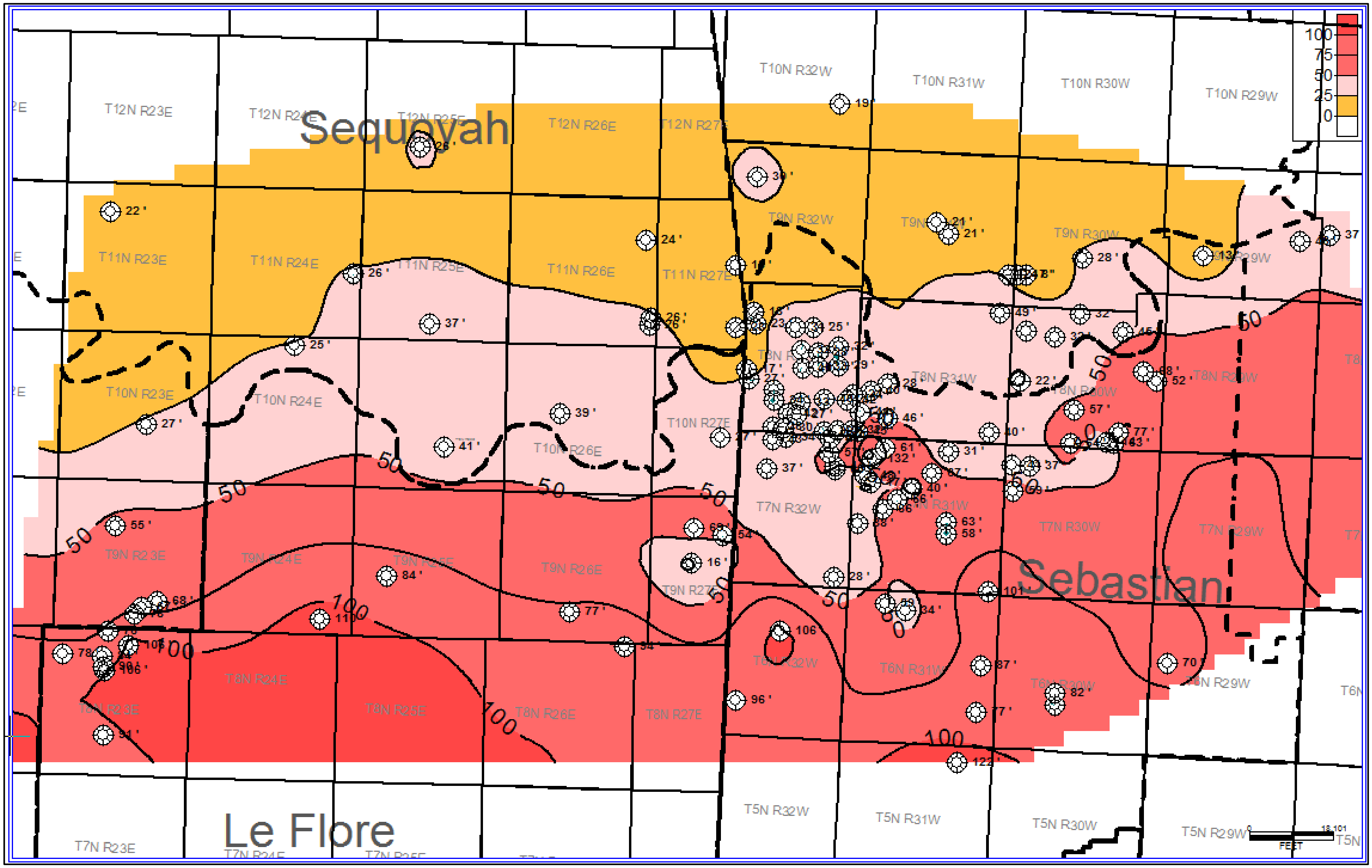


Figure 14.Chattanoga (Woodford) isopach map showing the overall thickening to the south trend. Contour interval is 25 ft.

Hunton Group

In the study area, the Hunton Group is represented by members of the Chimneyhill Subgroup and by the Penters (Sallisaw) Formation. It is important to note that the formations that make up the Chimneyhill Subgroup are normally correlated based on biostratigraphic data. In the subsurface, these formations are commonly referred by only their group name, the Chimneyhill. In the Arkansas subsurface, present Hunton members are often informally divided as the Hunton and Penters Chert. Amsden (1980) indicated that Hunton strata in the Bonanza Field consist of two distinct lithographic units: an upper chert and carbonate sequence with quartz-detritus and a lower group of dolomites and dolomitized organo-detrital dolomites (Amsden, 1980). The Chimneyhill strata of the Bonanza field are largely crystalline dolomites and heavily dolomitized organo-detrital limestones, which represent a continuation of the dolomite lithofacies present in eastern Oklahoma. In the Kinta and Bonanza Filed, the Penters Formation is often divided into an Upper and Lower section. For this study, when present, the Penters Formation was simply picked as Penters.

Hunton Group (Chimneyhill Subgroup and Penters Formation)

Within the study area, thickness values for the Hunton range from 0 feet in the southern portion of the study area to 362 feet in township 11N. Several wells only penetrated the upper portion of the Hunton Group and did not penetrate the Sylvan Shale. It was not uncommon to cease drilling when water was encountered in the Hunton; therefore isopach values were limited for the Hunton. Figure 14 is an isopach map of Hunton strata. The isopach values in Figure 14 include both the Penters (Sallisaw) Formation and the Chimneyhill members. The Hunton stratum is thickest in the northern part of the study area and gradually thins towards the South, eventually terminating to zero. Figure 15 is an isopach map displaying only the thickness of the Chimneyhill Subgroup

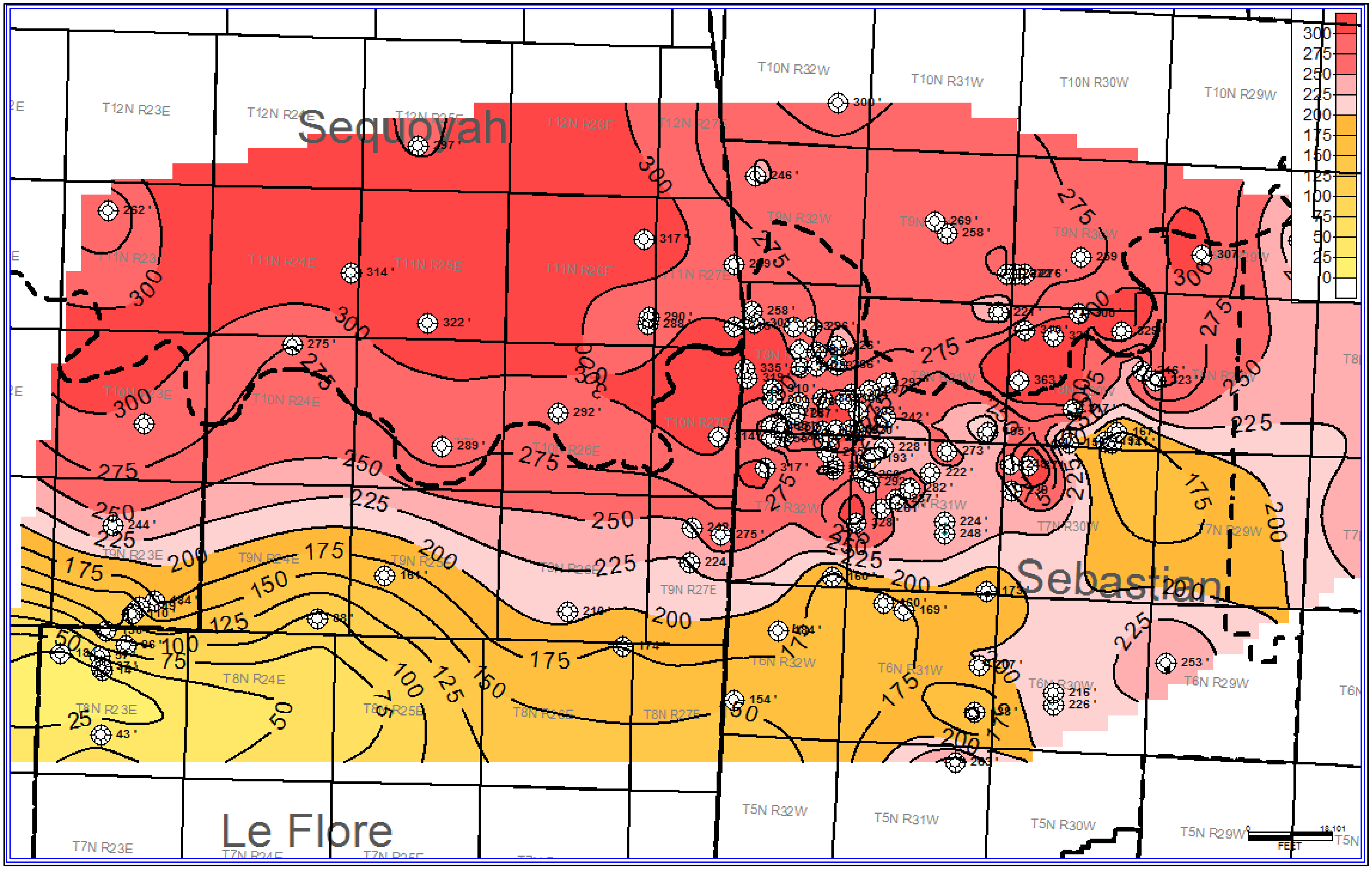


Figure 15. Hunton Isopach showing the general thinning to south of the Hunton. Contour interval is 25 ft.

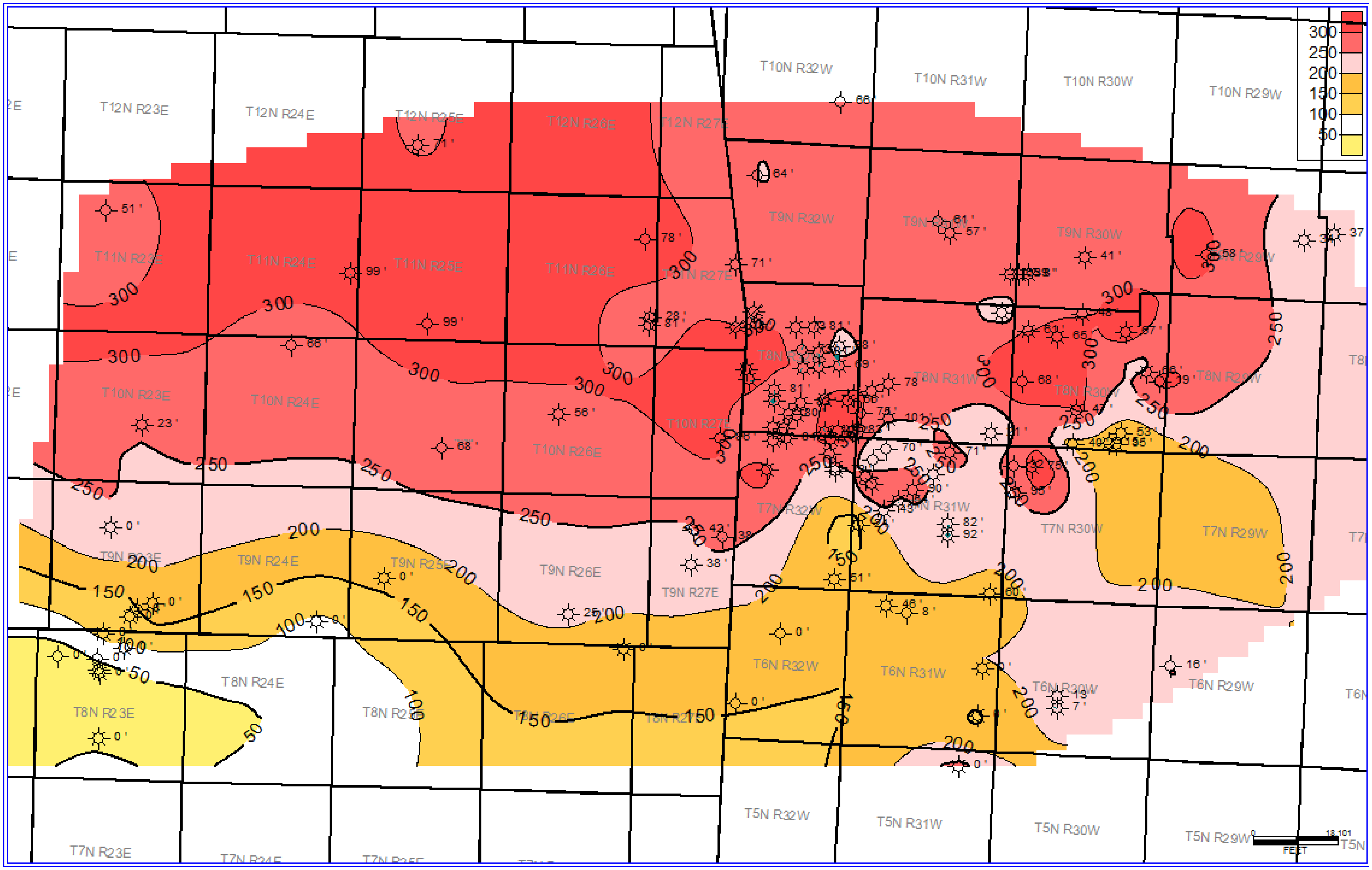


Figure 16. Isopach map of the Chimneyhill Subgroup. Contour interval is 50 ft.

Penters Chert (Sallisaw) Formation

The Penters Formation is only present in a portion of the study area therefore the number of isopach values for the Penters were also limited. Thickness values for the Penters range from 4 feet to 106 feet in thickness in the Sebastian County area. The thickness of the Penters (Sallisaw) Formation appears variable, likely due to the post Hunton erosion (Amsden, 1980). Figure 16 is an isopach map of the Penters Formation.

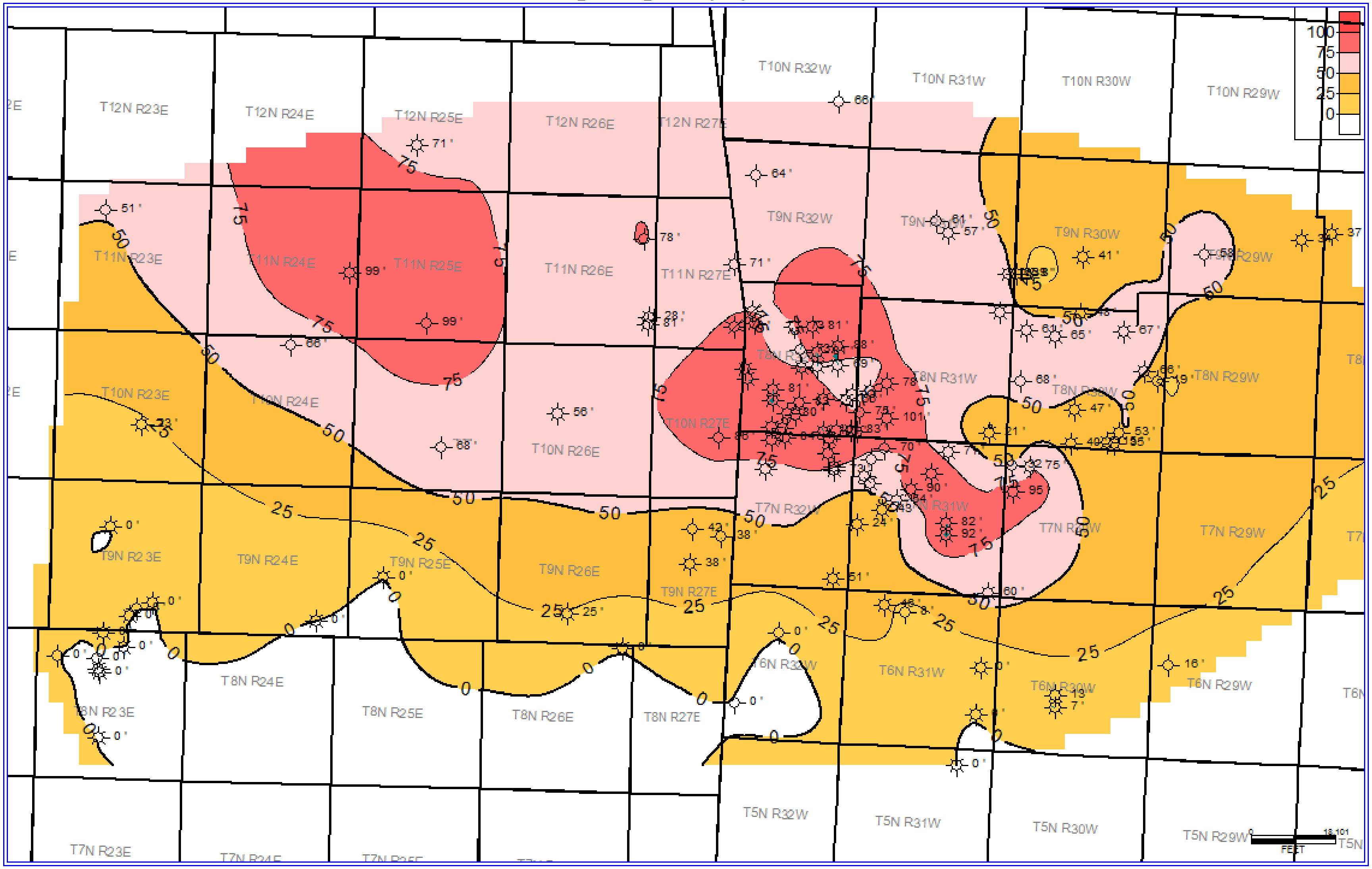


Figure 17. Isopach map of the Penters (Sallisaw) Formation. Contour interval is 25 ft.

Sylvan (Cason) Shale

Conformably underlying the Hunton Group is the Upper Ordovician Sylvan (Cason) Shale. Very few wells in the study area penetrated the underlying Sylvan; therefore an isopach map of the Sylvan was not created. In this part of the Arkoma Basin, thickness values for the Sylvan range from 1 to 50 feet. The average thickness in the study area is approximately 30 feet.

ELECTRIC LOG SIGNATURES

For this study, using their distinct signatures, three formations were identified and picked on the mechanical logs. These formations include the Woodford (Chattanooga) Shale, Hunton Group and Sylvan (Cason) Shale. This shale-carbonate-shale sequence is distinct on an electric log. On a gamma ray log, both the Woodford and Sylvan shale are often easily distinguished from the Hunton Group. The Woodford Shale has a very high gamma ray reading. This is due to the natural occurring gamma radiation in shale. All members of the Hunton Group have a much lower reading on a gamma ray log, when compared to that of the Woodford. In some areas, the Sylvan Shale grades into a strongly calcareous shale and argillaceous limestone. This gradation can make log correlation of the Sylvan exceptionally challenging (Rottmann, 2000) and did so in the study area. Members of the Chimneyhill group are also often unrecognizable in the subsurface and it is not an uncommon practice for these subgroups to not be differentiated in the subsurface. Figure 4 is a type log from central Oklahoma and illustrates the different stratigraphic units of the entire Hunton Group, excluding the Penters (Sallisaw) Formation. Figure 19 is a type log created from a well within the study area, the Roy Reed well in T9N, R26W, Sec. 28, Sebastian County, Arkansas. The Penters (Sallisaw) Formation is present in this area and is indicated on the type log. This log was used for correlating other wells in the study area.

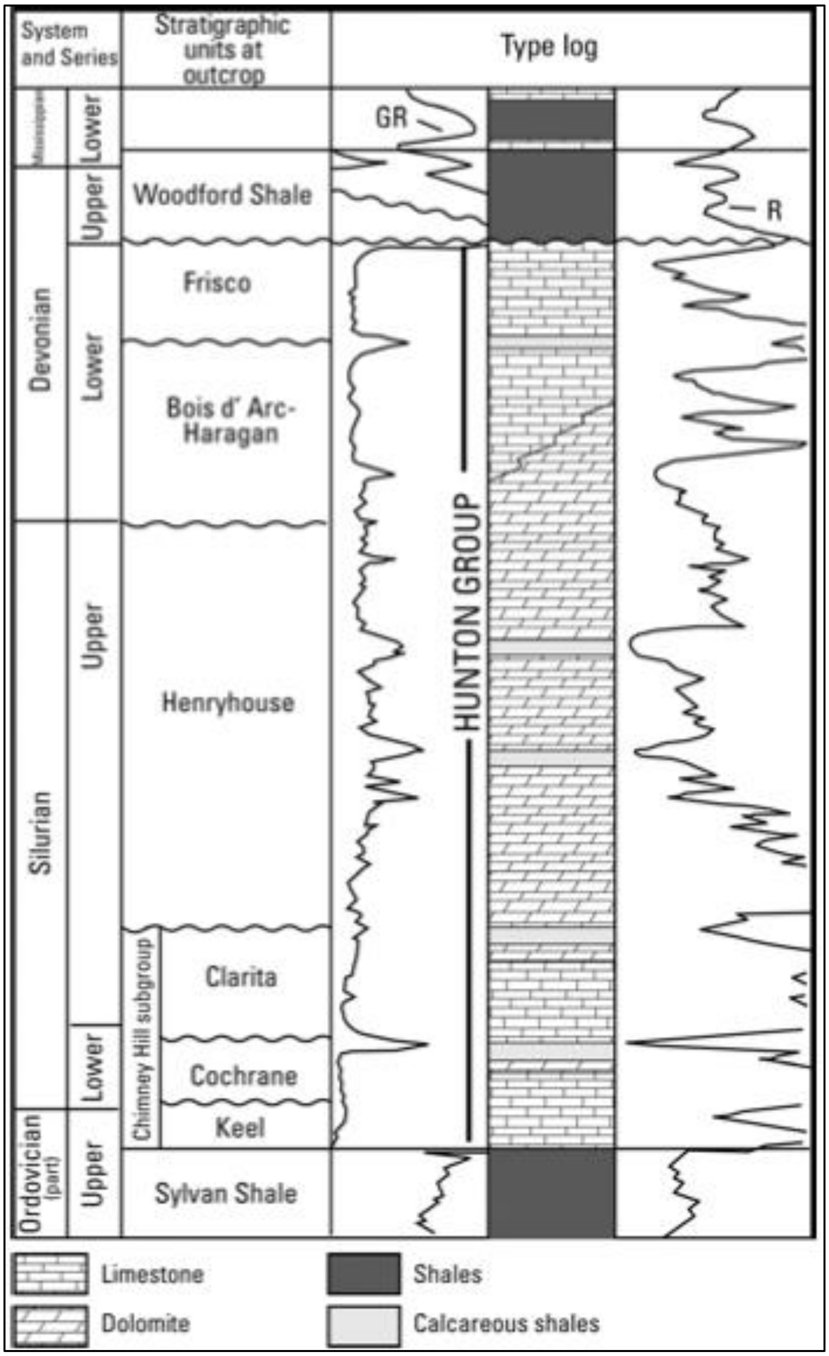


Figure 18. Type log of the Hunton Group showing gamma ray and resistivity (modified from Fritz and Medlock, 1994).

The SP curve of a well containing the Chimneyhill Subgroup, Henryhouse and Frisco Formations are typically recognizable, due to their distinctive lithologies. The sequence is an organo-detrital limestone/marlstone/organo-detrital limestone. This sequence, which is commonly referred to as a clean/shaly/clean, creates distinctive sigma shaped SP signature as shown in Figure 18 (Rottman, 2000).

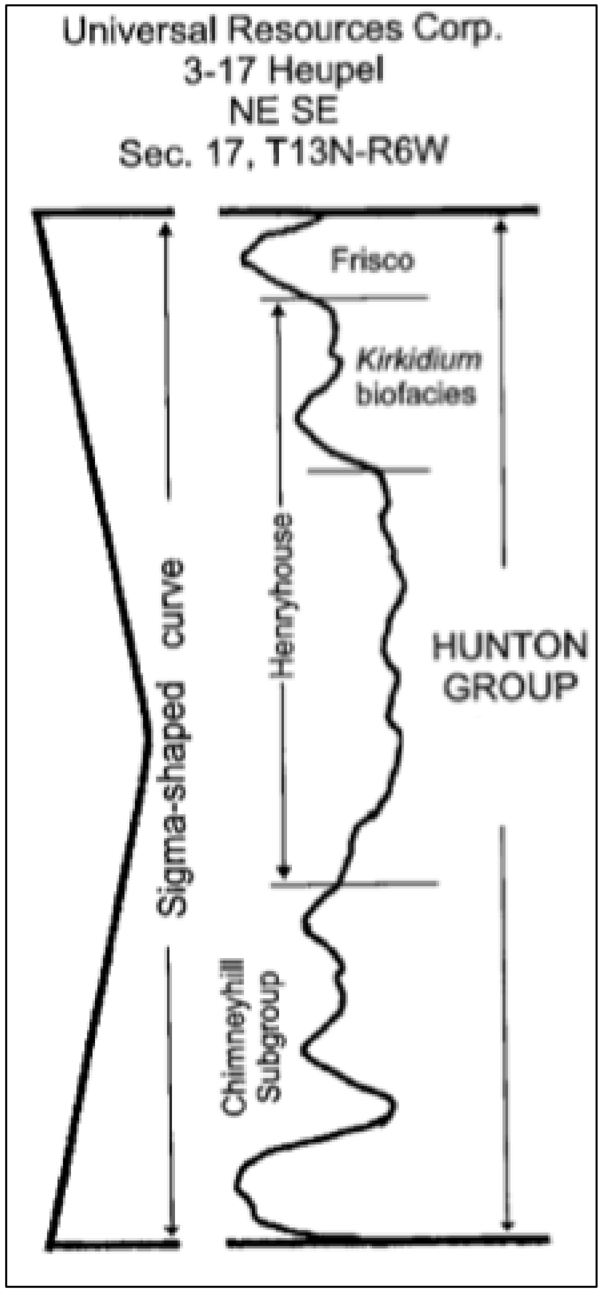


Figure 19. Silurian- Devonian Sigma shaped SP curve due to the clean/shaly/clean sequence (From Rottmann, 1993).

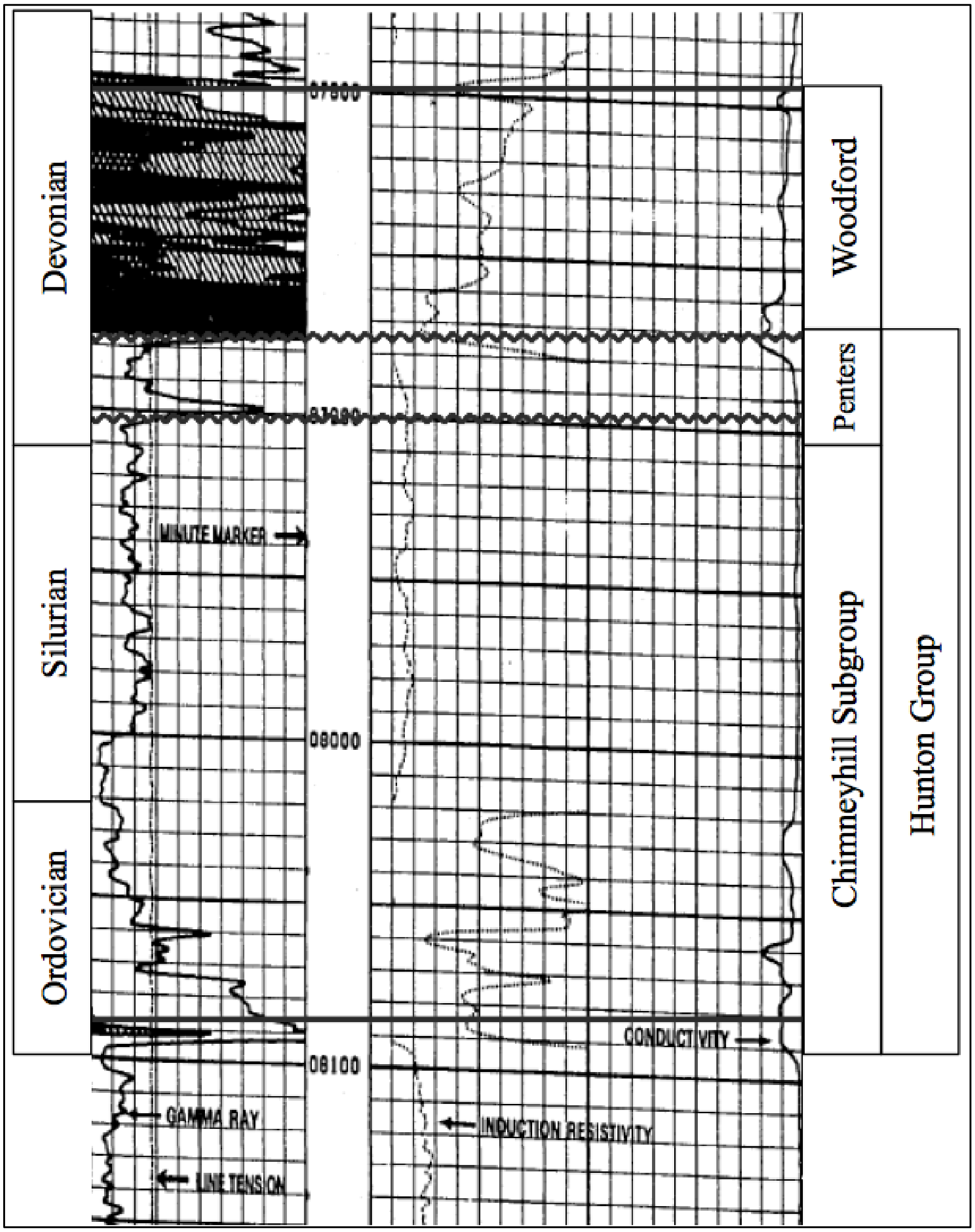


Figure 20. Type log Created from the Roy Reed well in T9N, R26W, Sec. 28

ANALYSIS OF CORED INTERVALS AND SAMPLES

<u>Evans No. 6</u>

The Evans No. 6 well is located in Haskell County Oklahoma and is part of the Kinta field in the Arkoma Basin (Figure 54). Stephens Production Company drilled the well in 2008. The well was drilled to a total depth of 6448 feet and was considered to be a dry hole when water was encountered.

A total of twelve sidewalls cores were recovered from the Evans No. 6 well. Two of the cores were from the Woodford (Chattanooga) Shale and the remaining ten cores were recovered from within the Hunton Group. Weatherford Laboratories in Houston, Texas analyzed the sidewall cores. The cores were analyzed in relation to porosity, permeability, grain density and X-ray diffraction. The collected data was used to create a graph showing permeability versus porosity (Figure 40). The two cores recovered from the Woodford Shale were crushed and powered. These shale samples were analyzed for: bulk density, grain density, water saturation, hydrocarbon saturation, and porosity. These samples were measured as received and after vacuuming drying at 180 degrees F. This data was also used to construct a graph (Figure 43) showing permeability versus porosity in the shale.

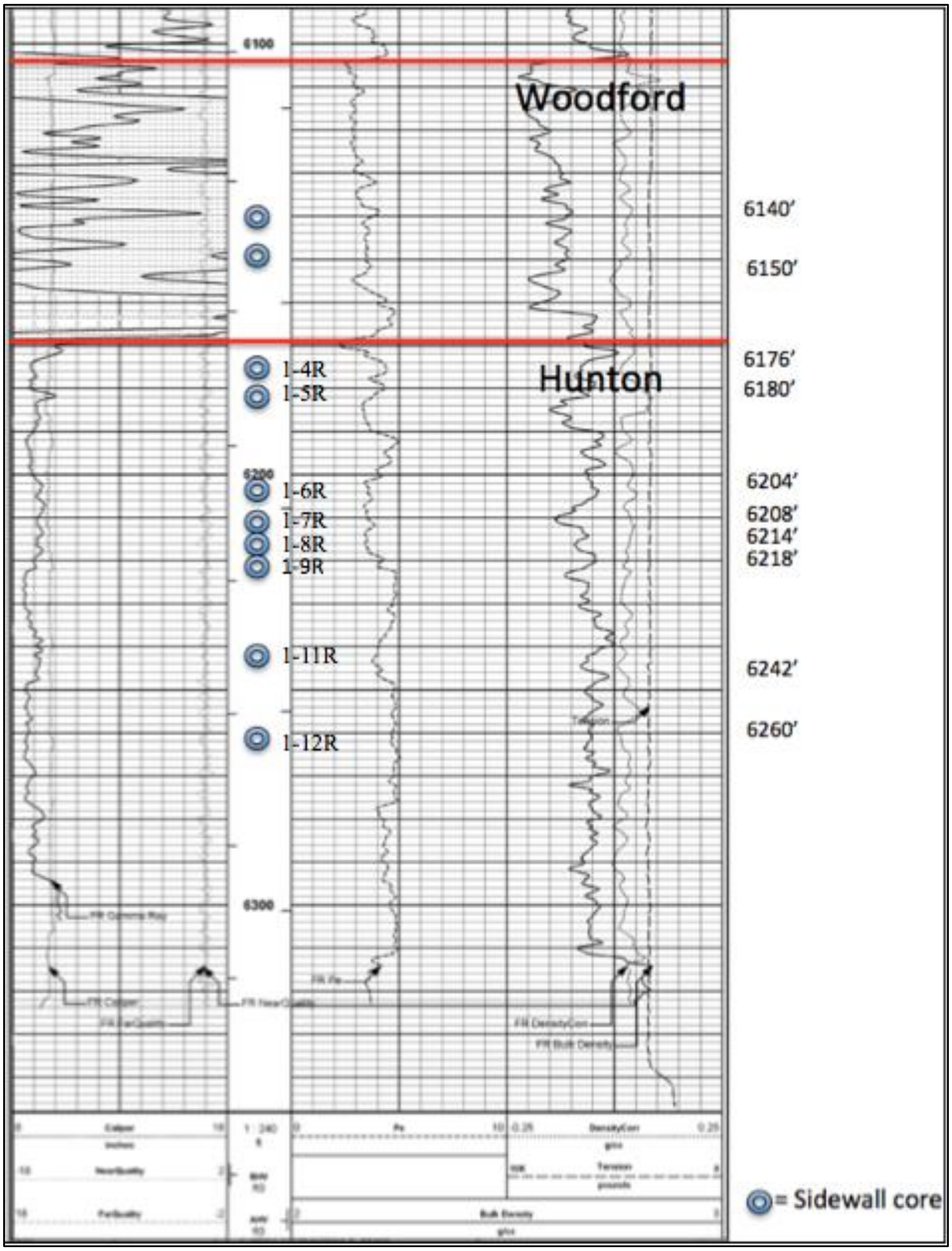


Figure 21. Wireline log indicating the measured depths at which the sidewall-cores were collected, in the Evans No. 6 well.

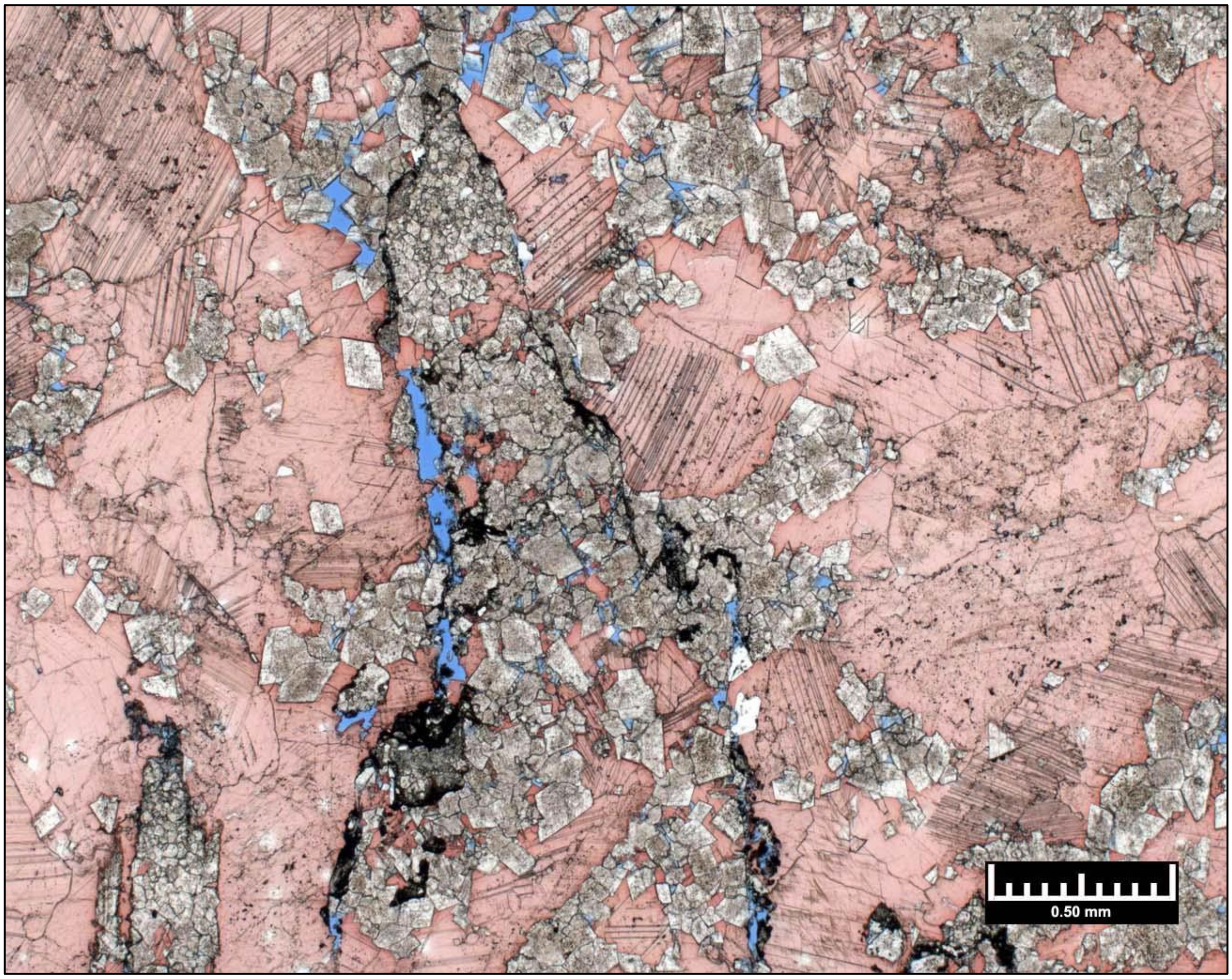


Figure 22. Sample 1-4R ,40x magnification photomicrograph. The survey photomicrograph is a low magnification view displays a typical view of rock composition, which is dominated by calcite (red) with lesser dolomite (tan). Note the organic concentrations (opaque) defining the jagged stylolitic seam. Porosity (blue) is poorly developed overall.

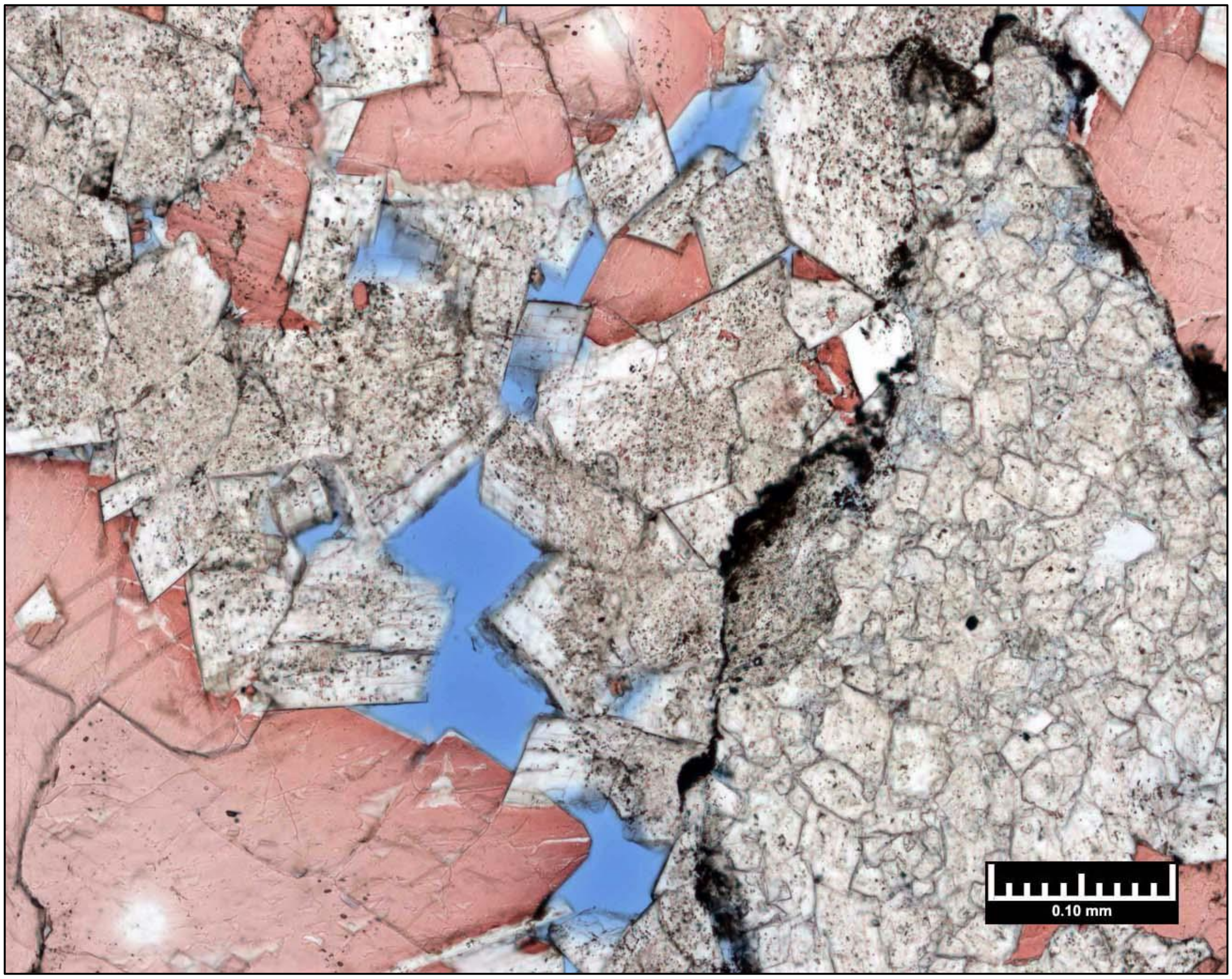


Figure 23 Sample 1-4R, 200x magnification photomicrograph The high magnification photomicrograph provides a magnified view of intercrystalline porosity, which are regions between dolomite rhombs. Note the dark organic material comprising the stylolitic seams. Calcite spar is also abundant in this limestone and exists as both a cement and as replaced allochems.

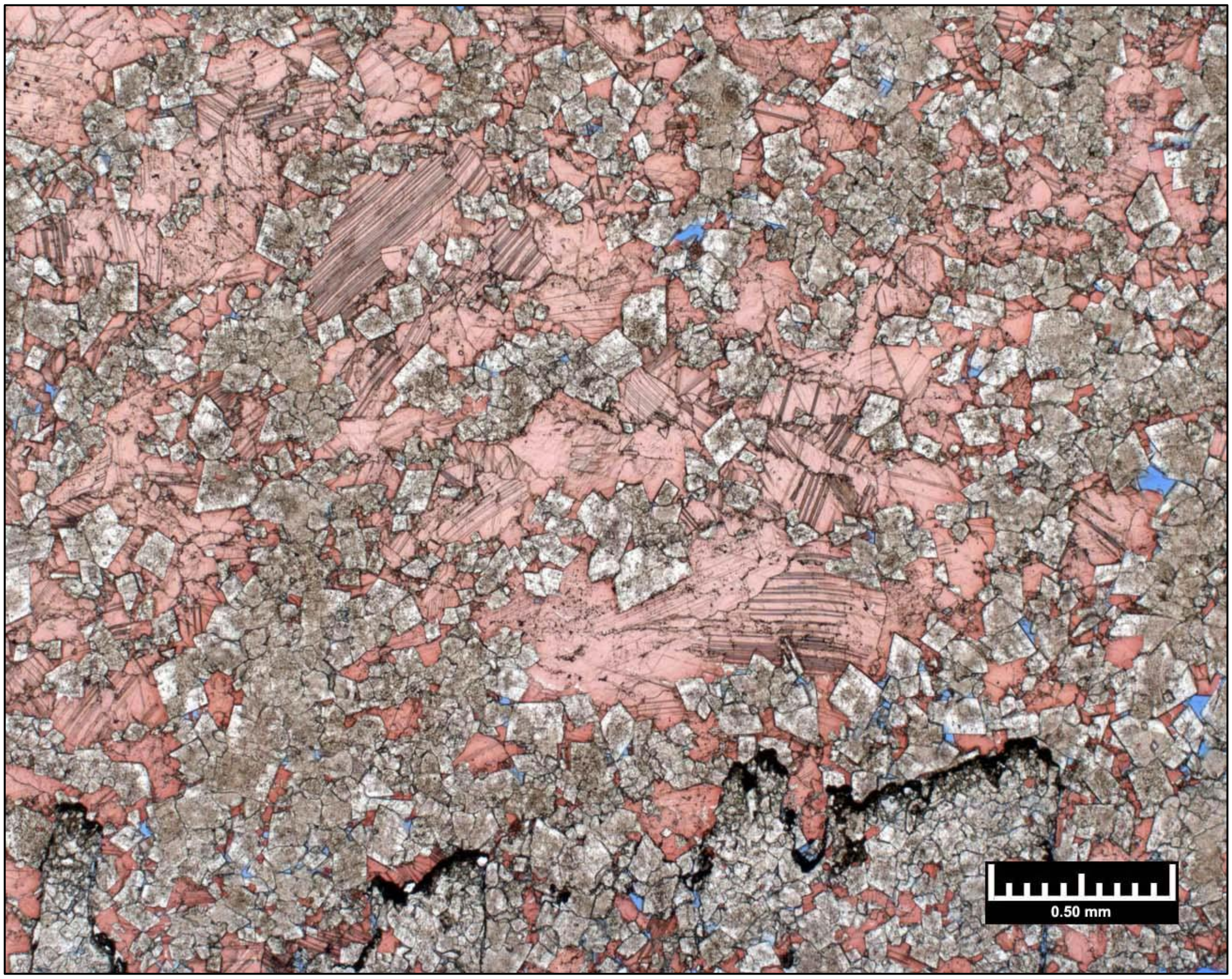


Figure 24. Sample 1-5R, 40x magnification photomicrograph. The survey photomicrograph is a low magnification view, which displays a typical view of rock composition. This sample is dominated by calcite (red) with a lesser amount of dolomite (tan). Note the organic concentrations (opaque) defining the jagged stylolitic seam. Porosity (blue) is poorly developed, overall.

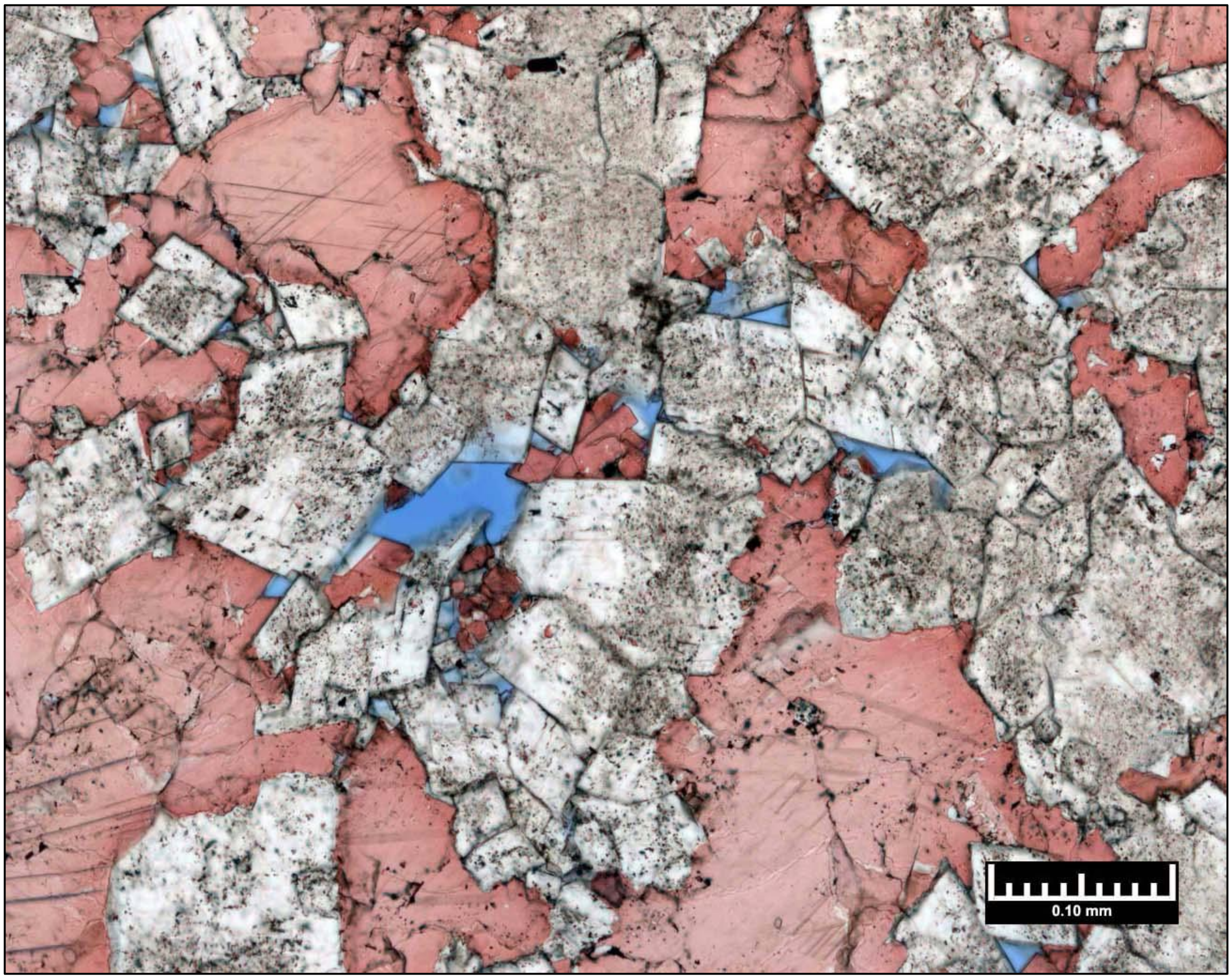


Figure 25. Sample 1-5R, 200x magnification photomicrograph. The high magnification photomicrograph provides a magnified view of porosity found in intercrystalline regions between dolomite rhombs. Note the dark centers of the well-formed dolomite crystals. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.

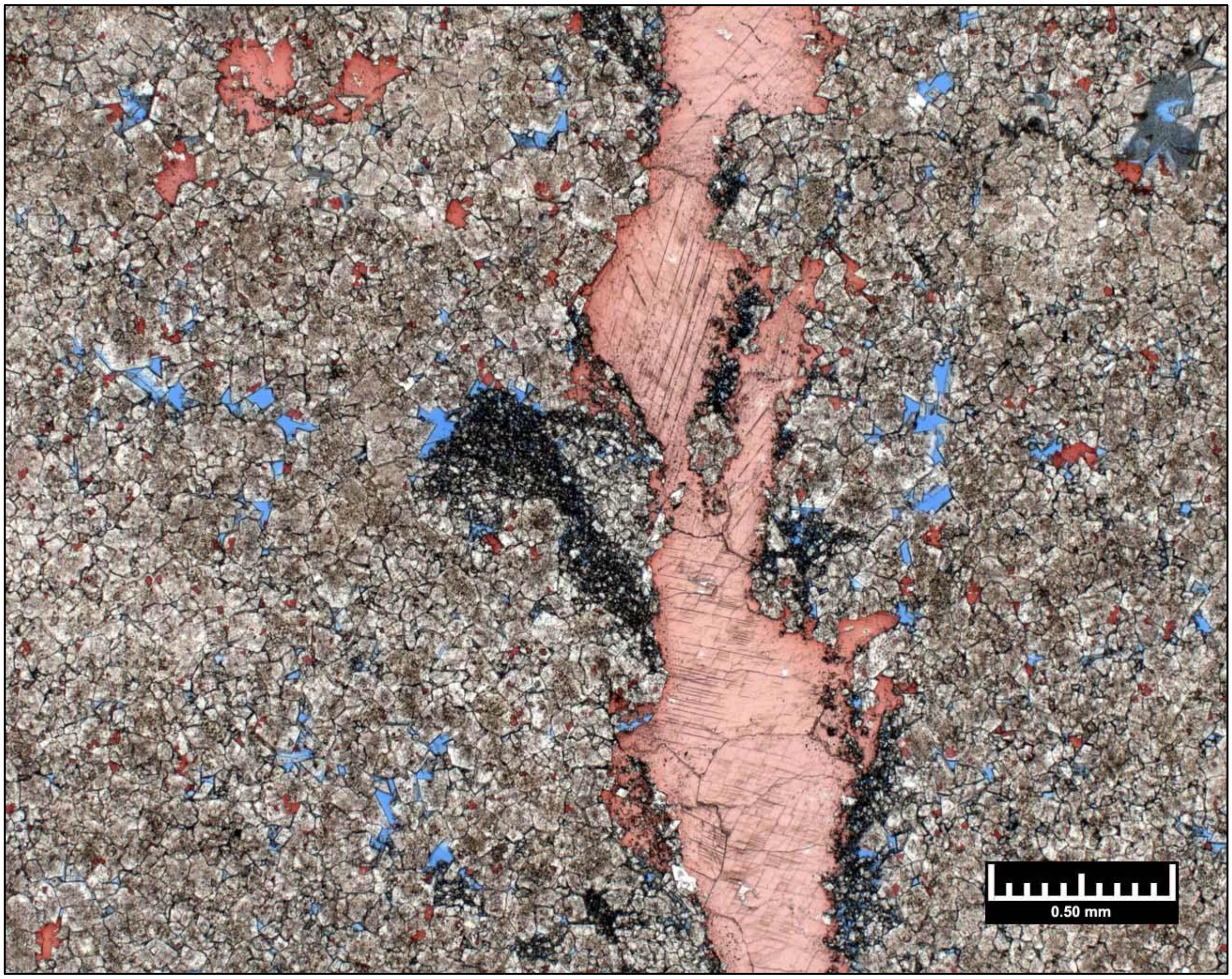


Figure 26. Sample 1-6R, 40x magnification photomicrograph. The survey photomicrograph is a low magnification view, which displays a typical view of rock composition. The sample is dominated by dolomite (tan) with lesser amounts of calcite (red). Note the organic concentrations (opaque) and calcite filling the stylolitic seam. Porosity (blue) is poorly developed, overall, in this limestone.

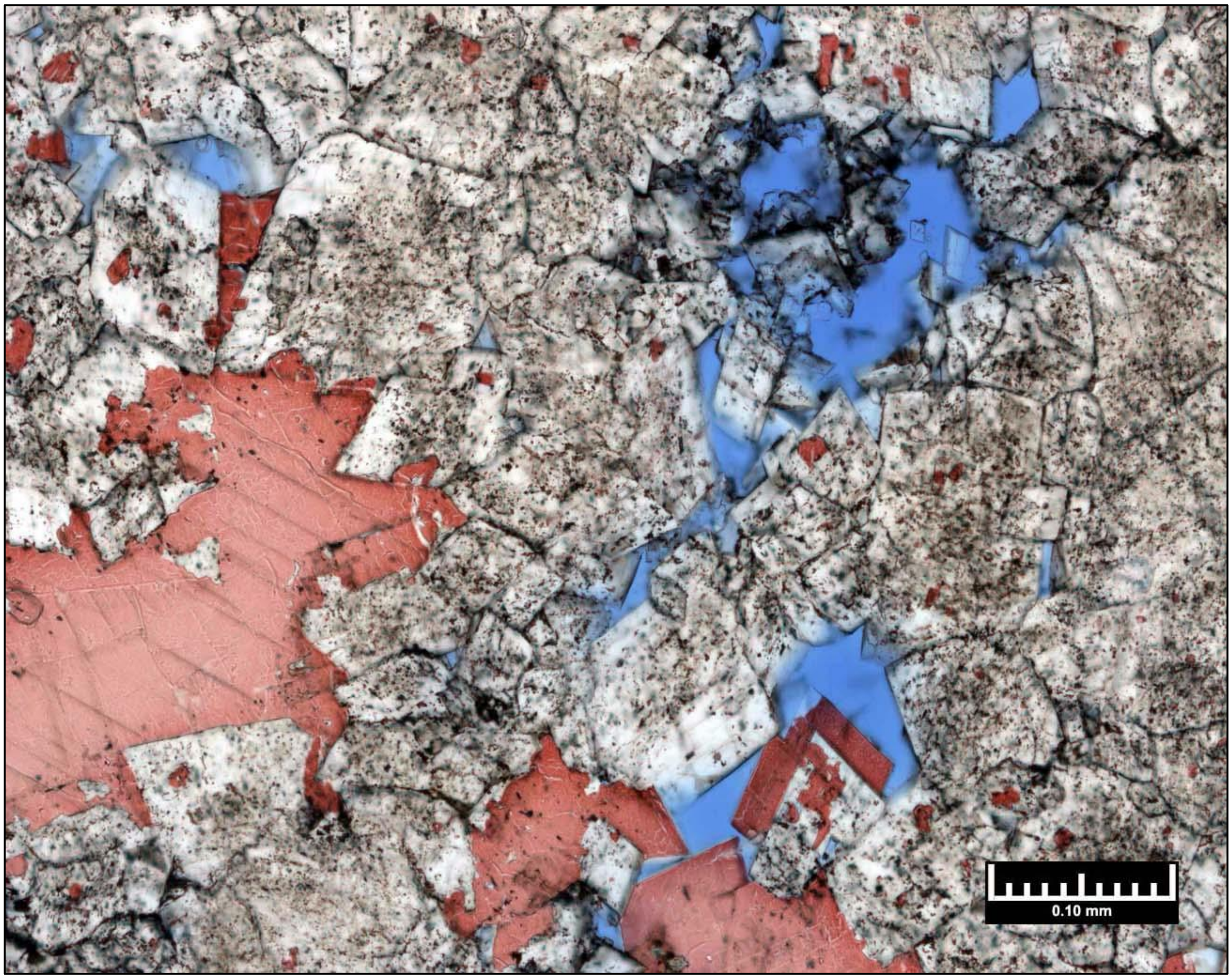


Figure 27. Sample 1-6R, 200x magnification photomicrograph. The high magnification photomicrograph provides a magnified view of organic concentration and euhedral rhombohedra with dark centers. Porosity is found in intercrystalline regions between dolomite rhombs. Calcite spar is abundant as cement between dolomite rhombs.

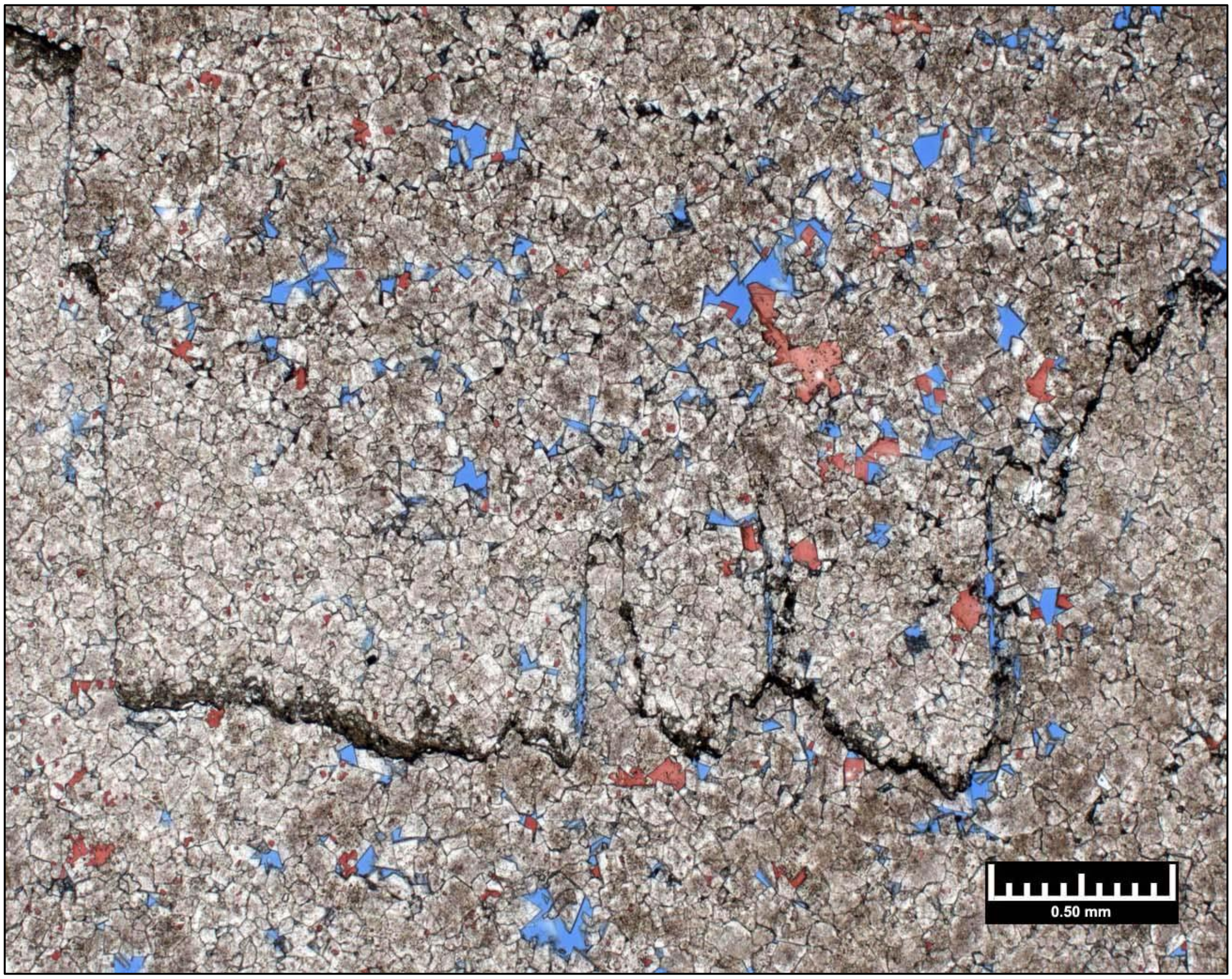


Figure 28. Sample 1-7R, 40x magnification photomicrograph. The low magnification survey photomicrograph features a slightly calcitic dolostone. Dolomite (tan) is dominant; calcite spar (stained red) mainly fills molds. Moldic areas not infilled retain pore space (blue) Note the organic concentrations (opaque) defining the jagged stylolitic seam.

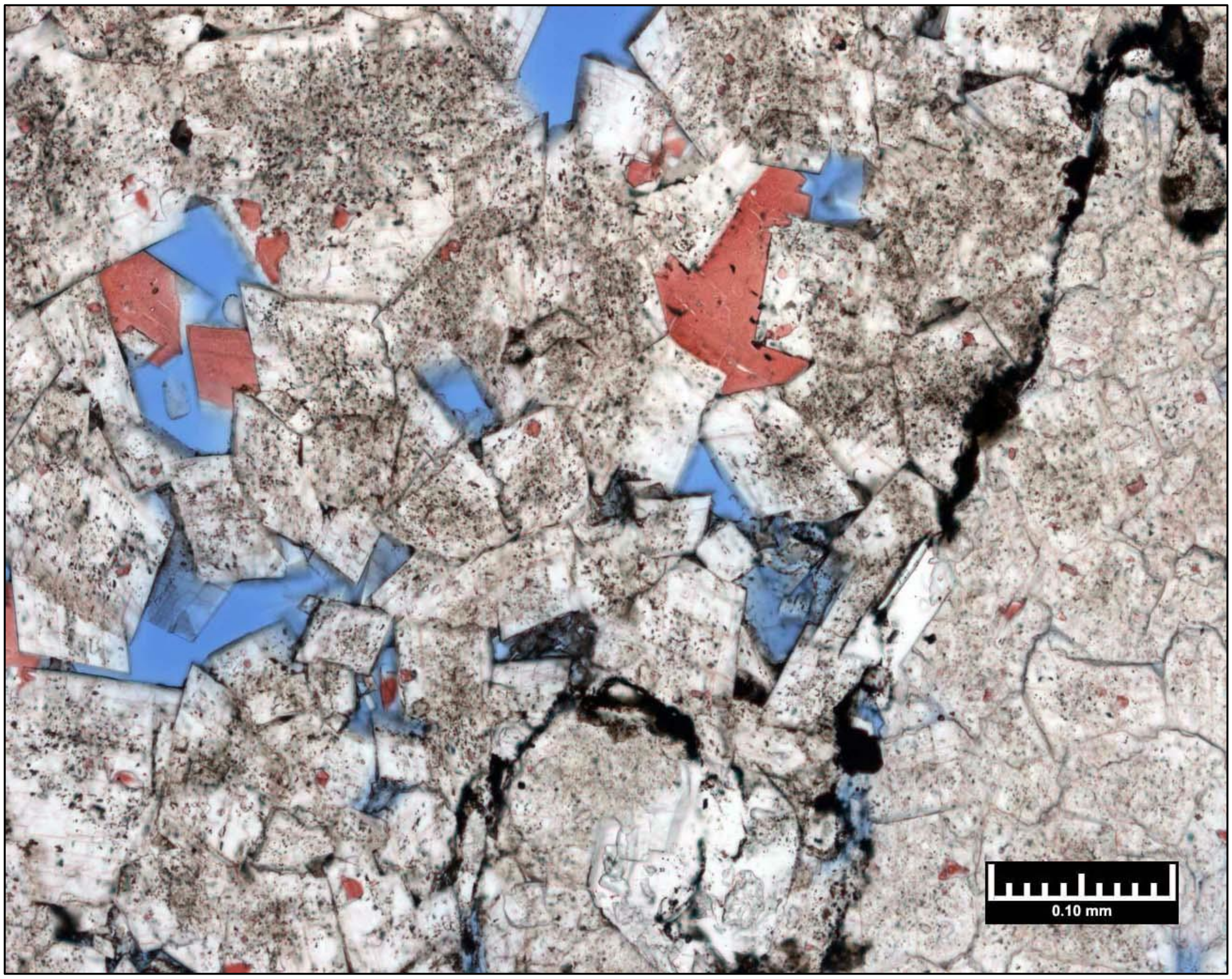


Figure 29. Sample 1-7R, 200x magnification photomicrograph. This photomicrograph provides a magnified view of the intercrystalline porosity between dolomite rhombs and dark organic material along the stylolitic seam. Note the abundant amount of well-formed dolomite rhombs. Porosity is moderately developed throughout this sample.

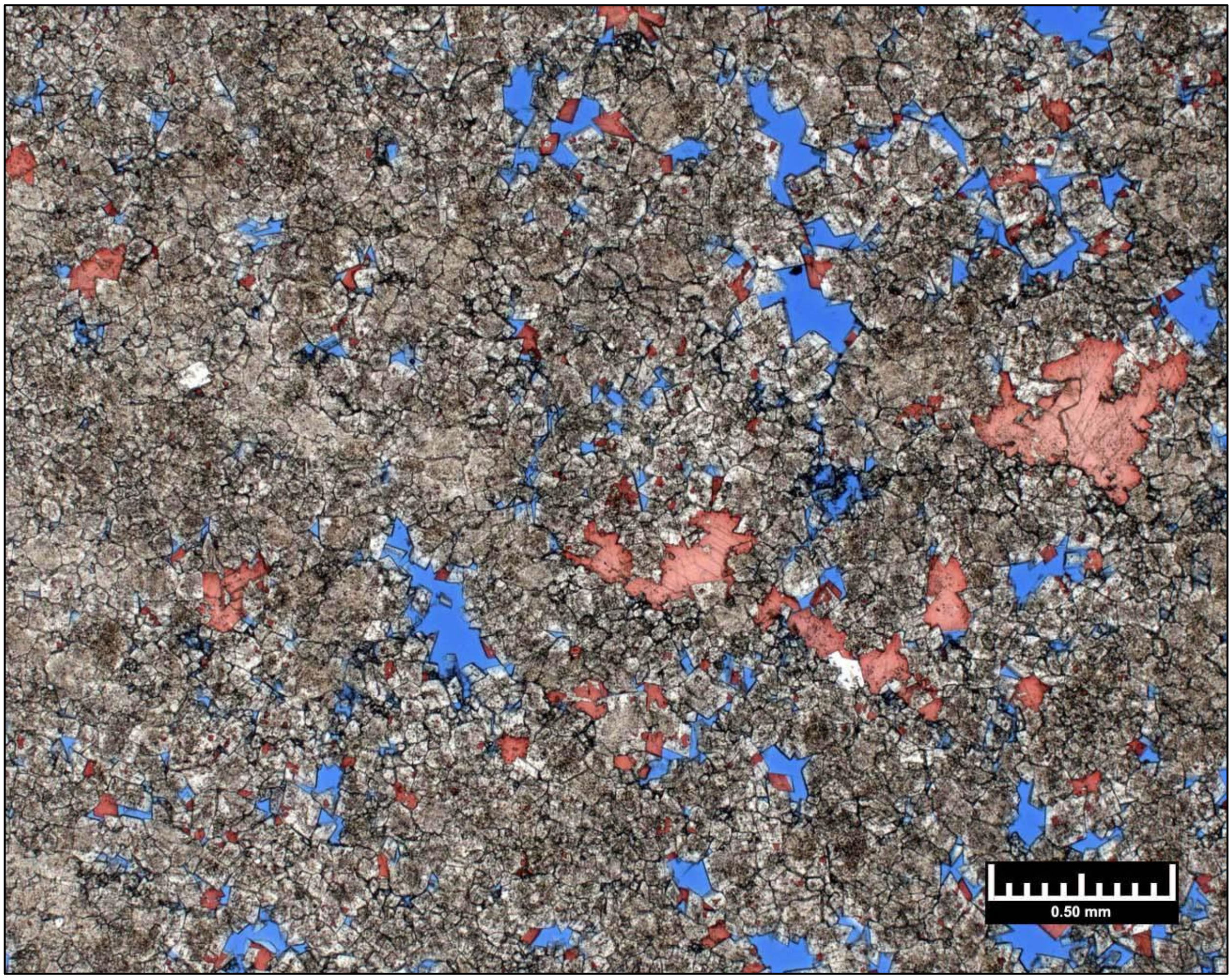


Figure 30. Sample 1-8R ,40x magnification photomicrograph. The low magnification survey photomicrograph features a slightly calcitic dolostone. Dolomite (tan) is dominant; calcite spar (stained red) mainly fills molds. Moldic areas not infilled retain pore space (blue). Minor organic material mixed with clay (appear dark).

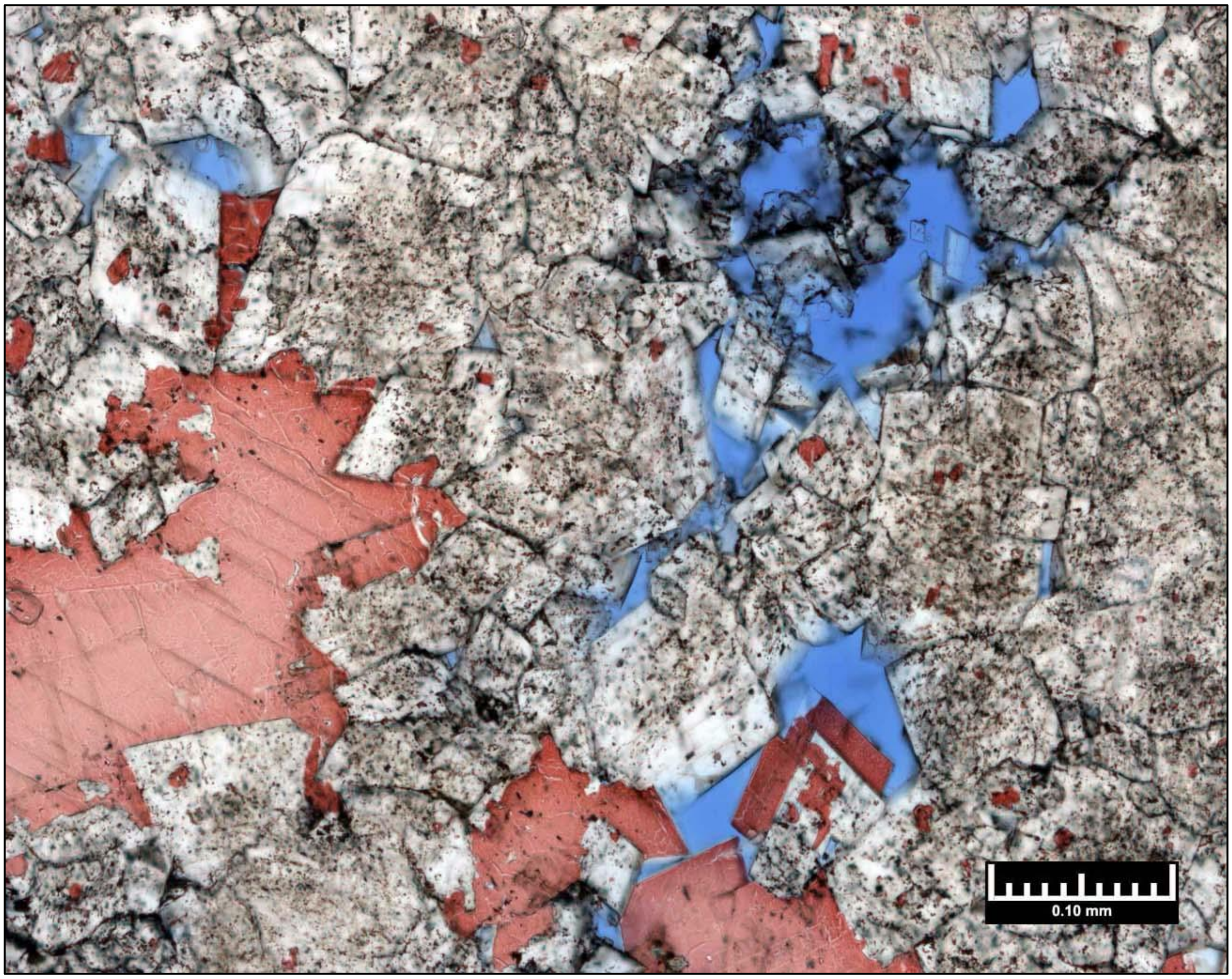


Figure 31. Sample 1-8R, 200x magnification photomicrograph. This photomicrograph provides a magnified view of the pore-filling calcite spar and abundant dolomite. Porosity is moderately developed throughout this sample. Note the detail of the authigenic clay/organic mix.

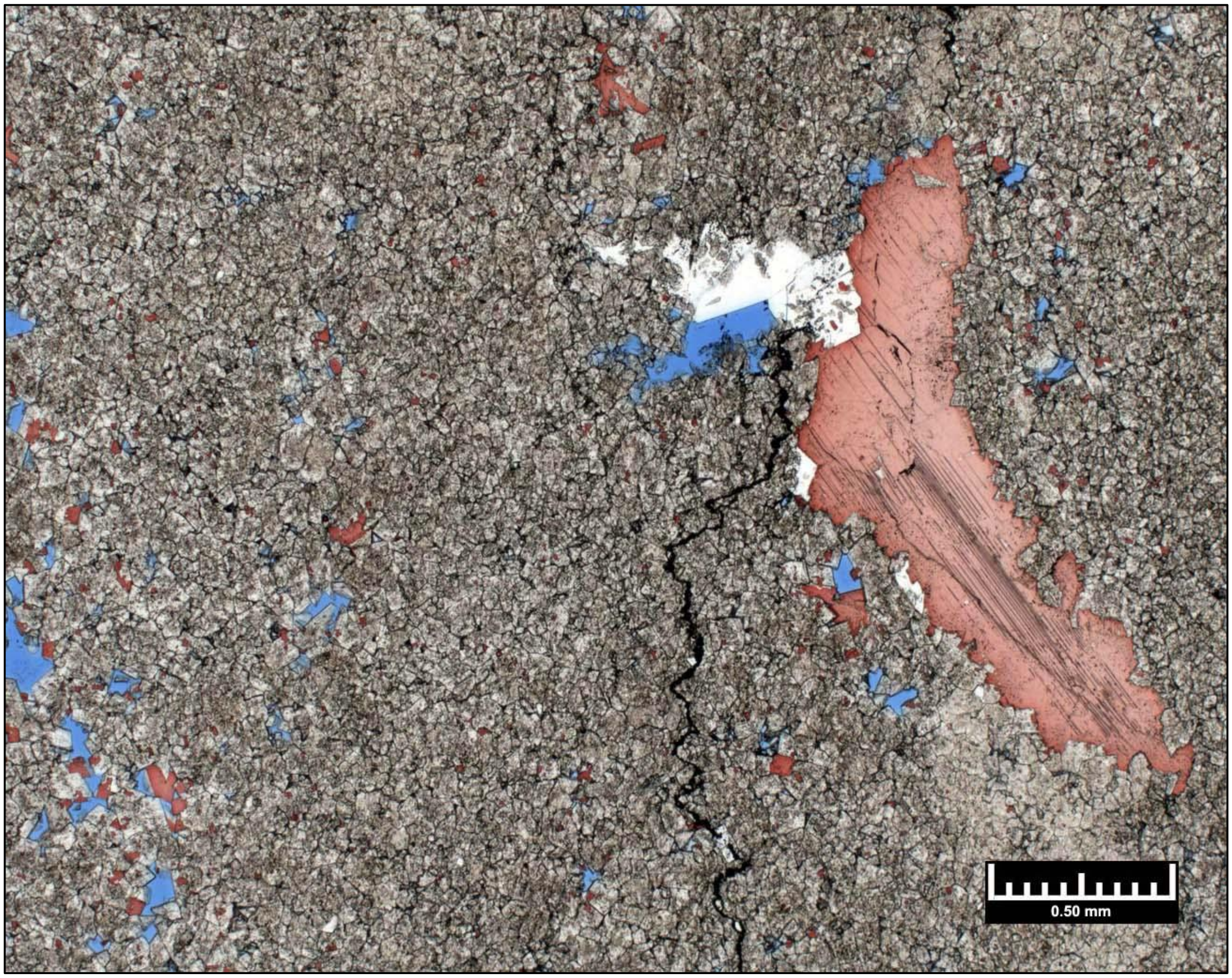


Figure 32. Sample 1-9R, 40x magnification photomicrograph. The low magnification survey photomicrograph features a slightly calcitic dolostone. Dolomite (tan) is dominant; calcite spar (stained red) mainly fills molds. Intercrystalline areas not infilled retain pore space (blue). Minor organic material mixed with clay along stylotic seam.

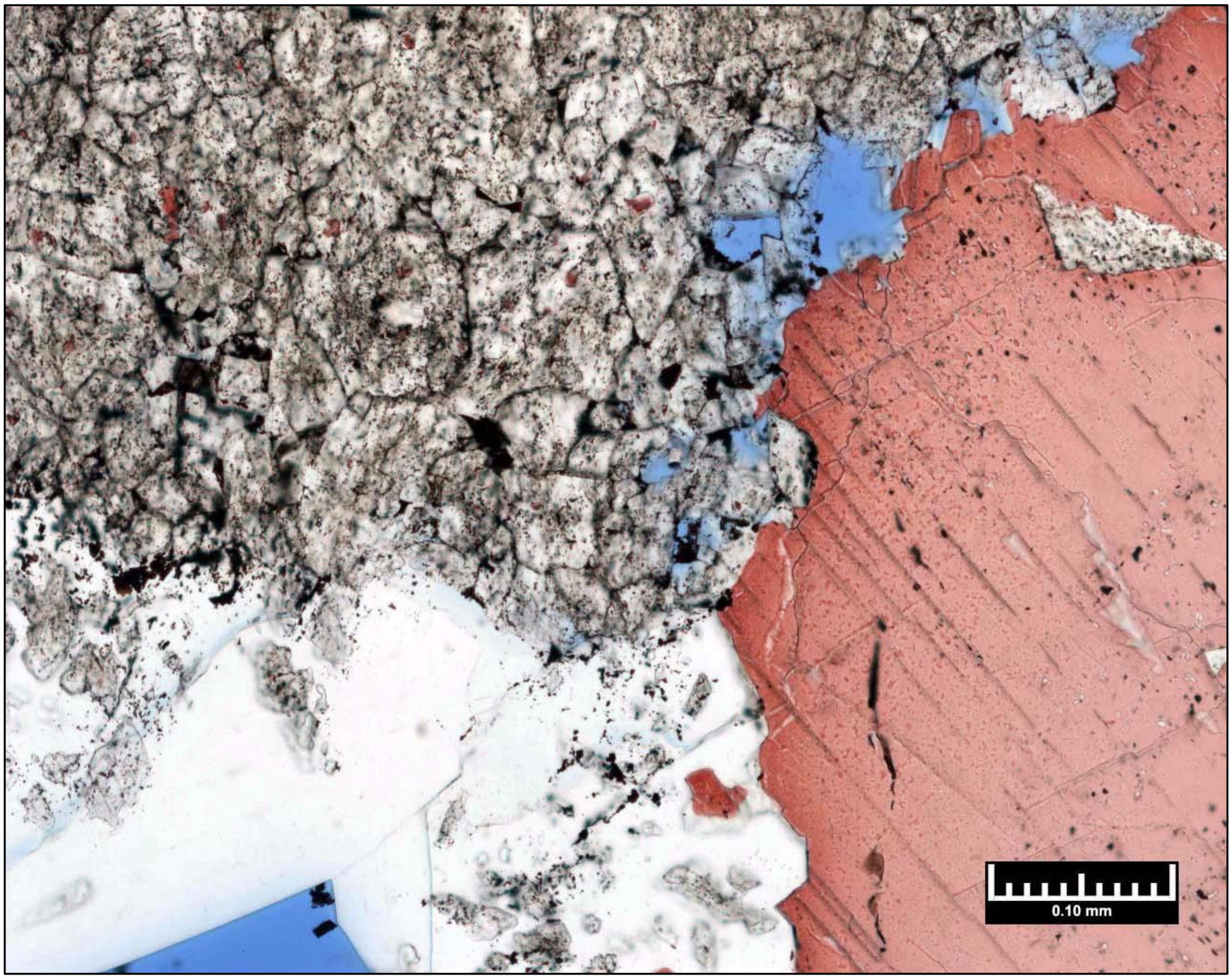


Figure 33. Sample 1-9R, 200x magnification photomicrograph. This photomicrograph provides a magnified view of the moldic pore-filling calcite spar and abundant dolomite Porosity is poorly to moderately developed throughout this sample. Note the calcite filling pores between dolomite rhombs.

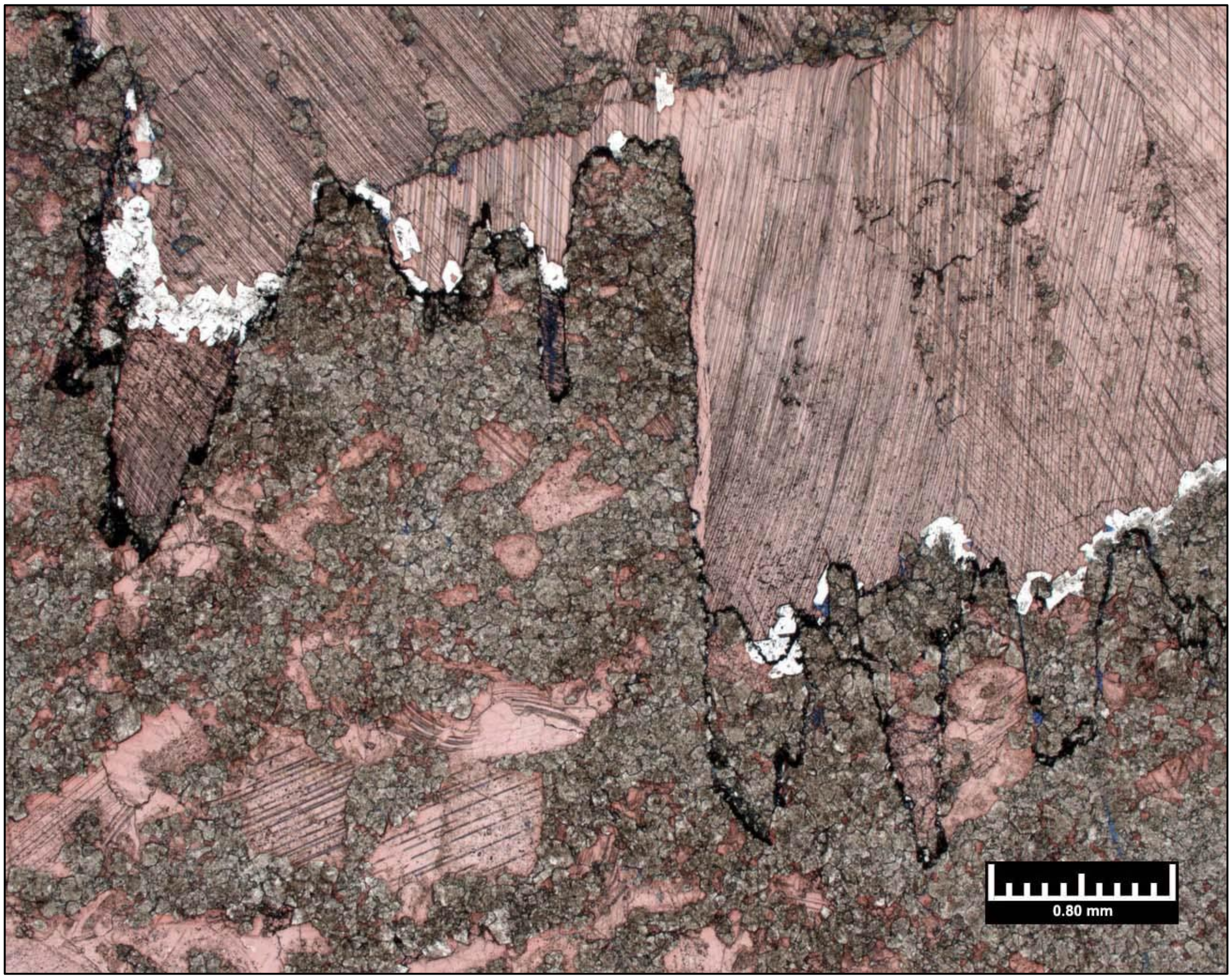


Figure 34. Sample 1-10R , 25x magnification photomicrograph. The survey photomicrograph is a low magnification view of rock composition, which is dominated by calcite (red) with lesser dolomite (tan). Note the organic concentrations defining the jagged stylolitic seam. Porosity (blue) is poorly developed and only exists along the stylolitic seam.

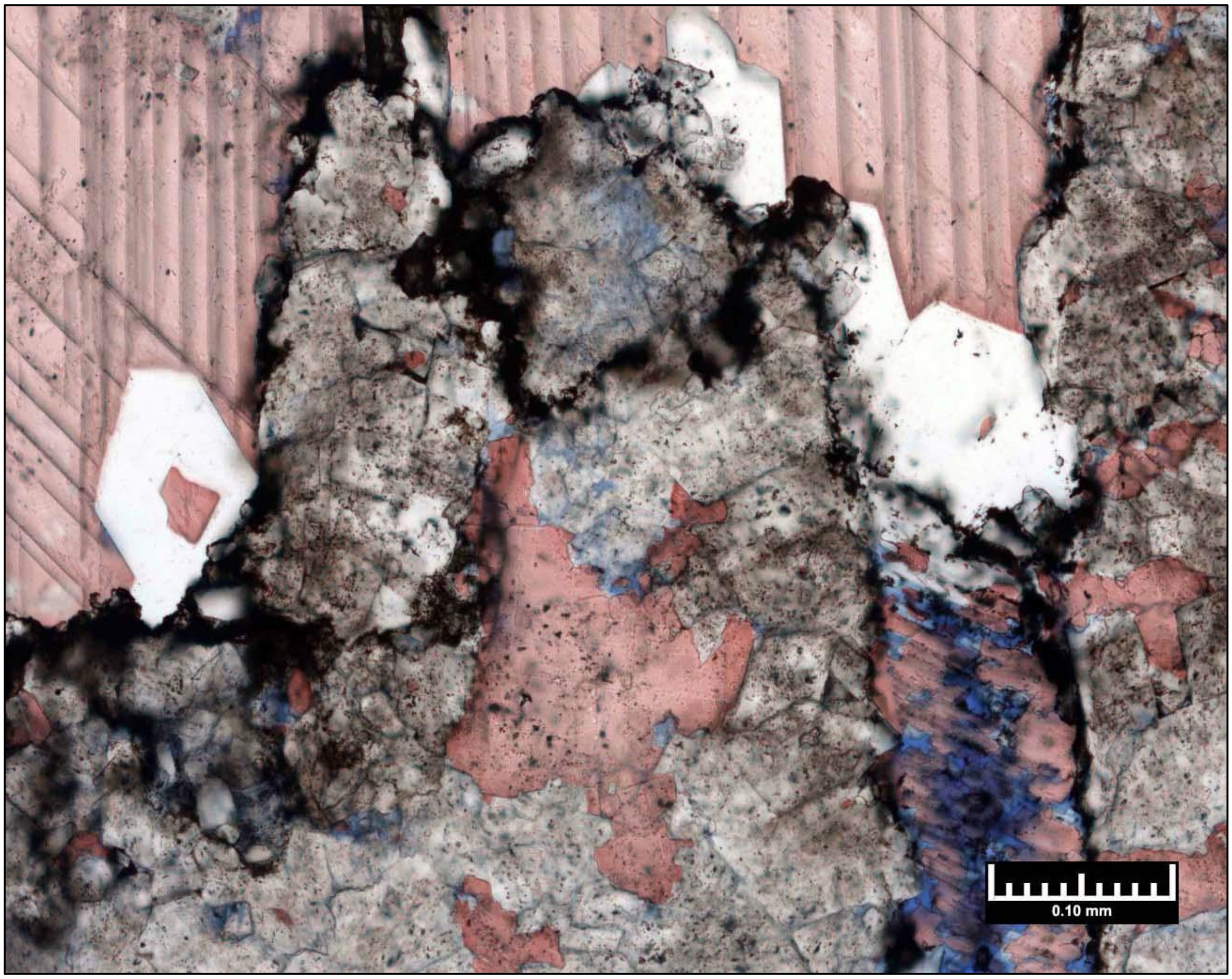


Figure 35. Sample 1-10R, 200x magnification photomicrograph. The high magnification photomicrograph provides a magnified view along the stylolitic seam. Note the dark organic material comprising the seam. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.

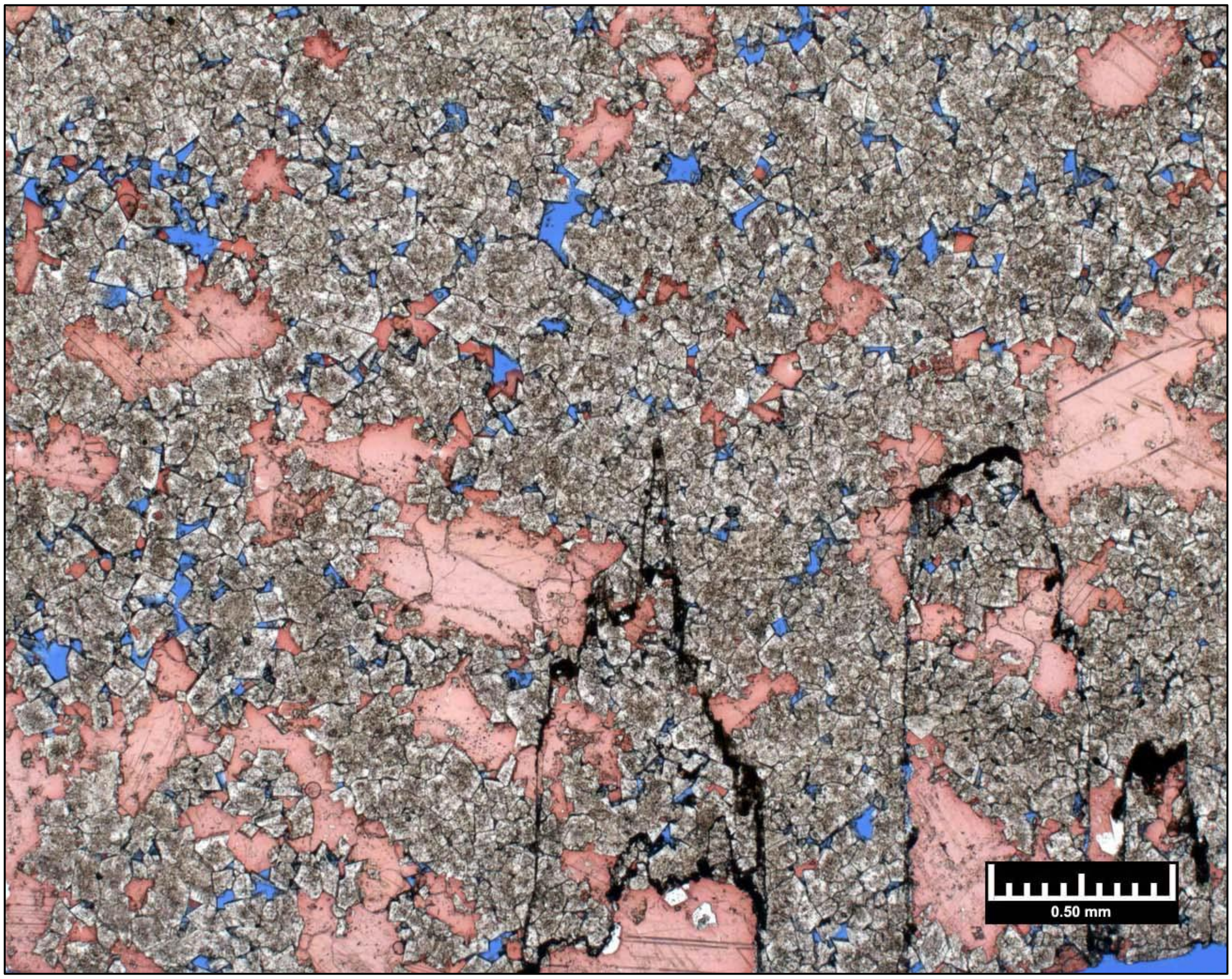


Figure 36. Sample 1-11R, 40x magnification photomicrograph. The survey photomicrograph is a low magnification view of rock composition, which contains generally equal amounts of calcite (red) and dolomite (tan). Note the organic concentrations (opaque) defining the jagged stylolitic seam. Porosity (blue) is poorly developed, overall, in this limestone.

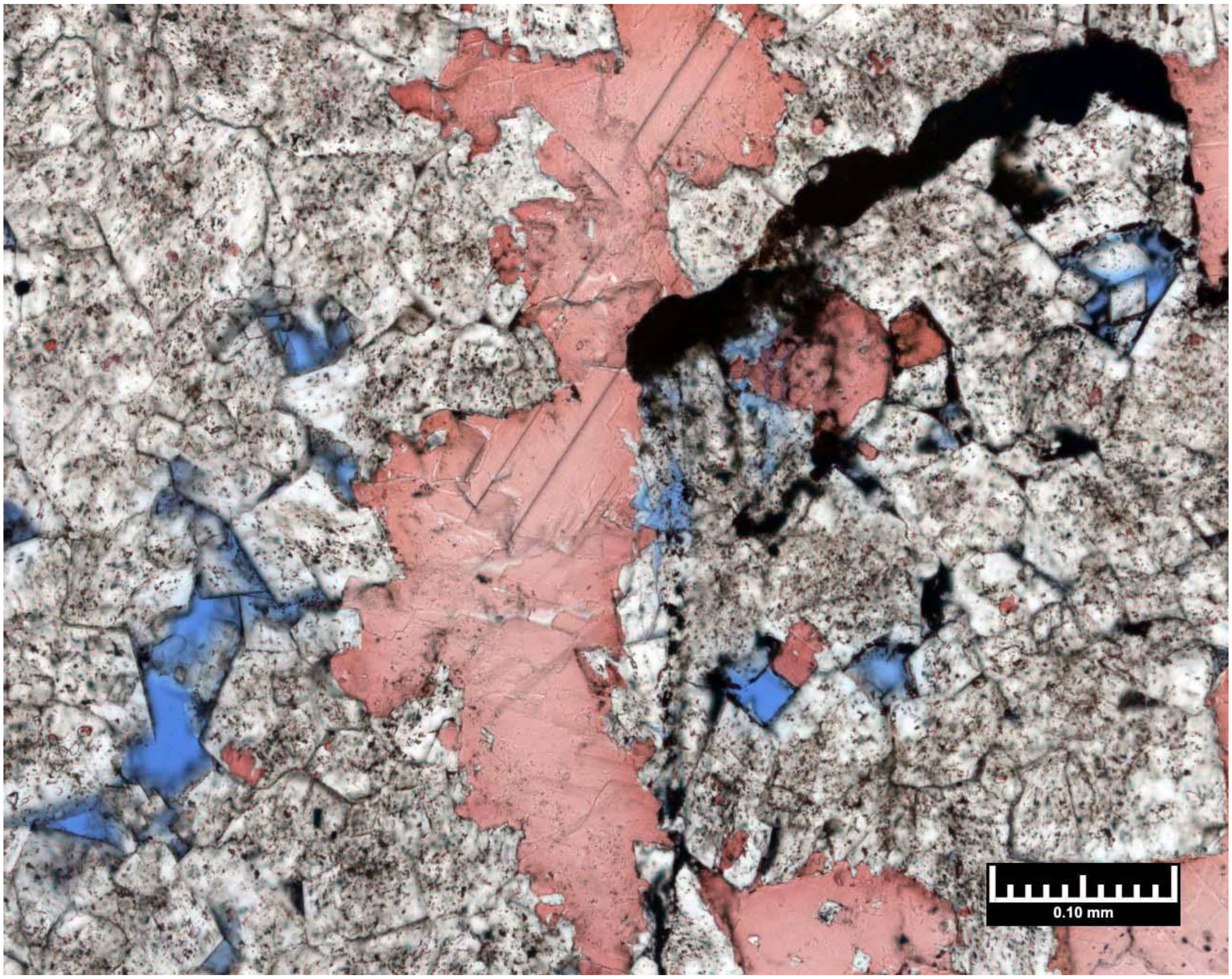


Figure 37. Sample 1-11R, 200x magnification photomicrograph. The high magnification photomicrograph provides a magnified view of Porosity that is found in intercrystalline regions between well-formed dolomite rhombs Note the dark organic material comprising the stylolitic seam. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.

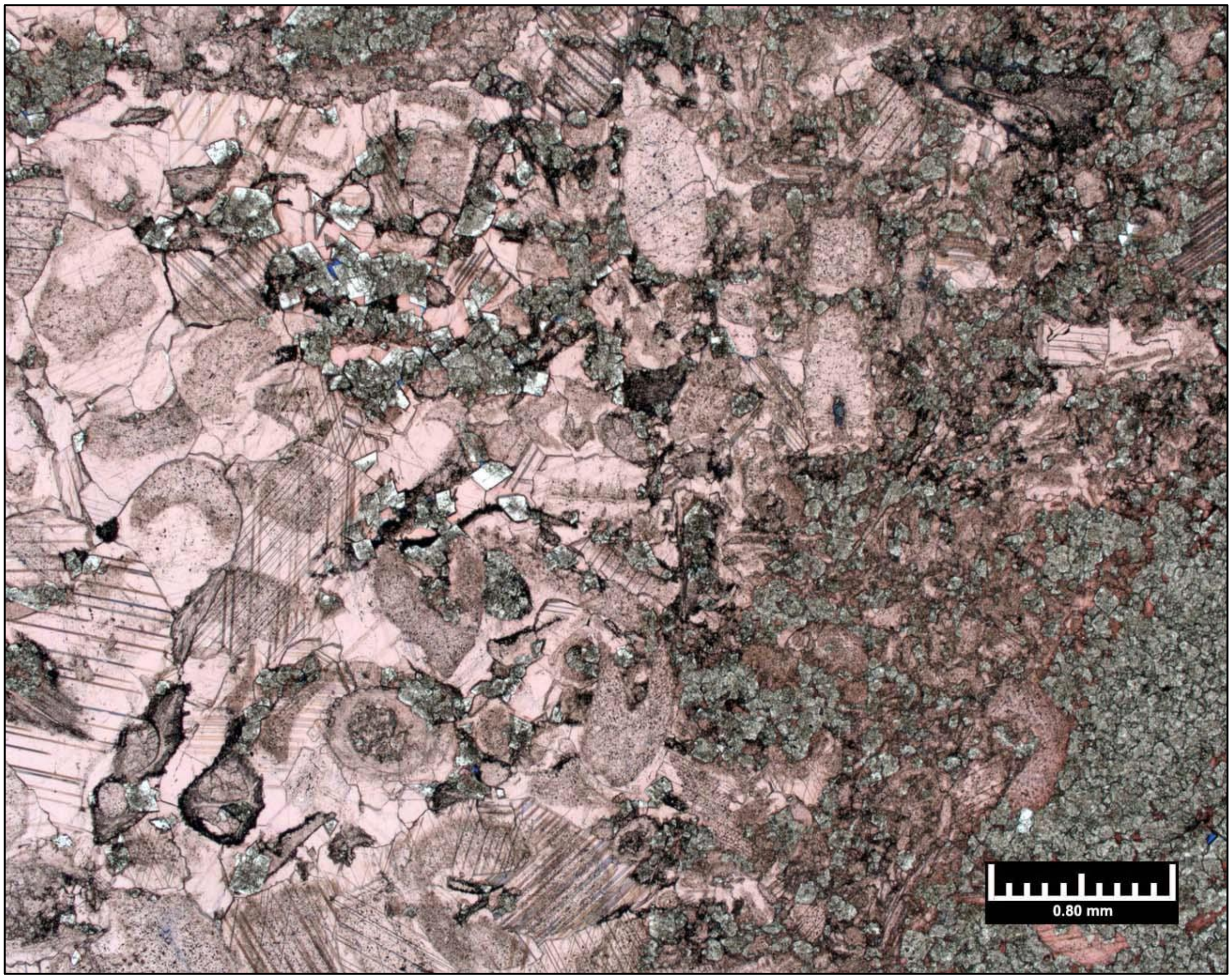


Figure 38. Sample 1-12R, 25x magnification photomicrograph. The survey photomicrograph is a low magnification view displaying the rock composition, which is dominated by calcite (red) with lesser dolomite (tan). Porosity (blue) is almost nonexistent.

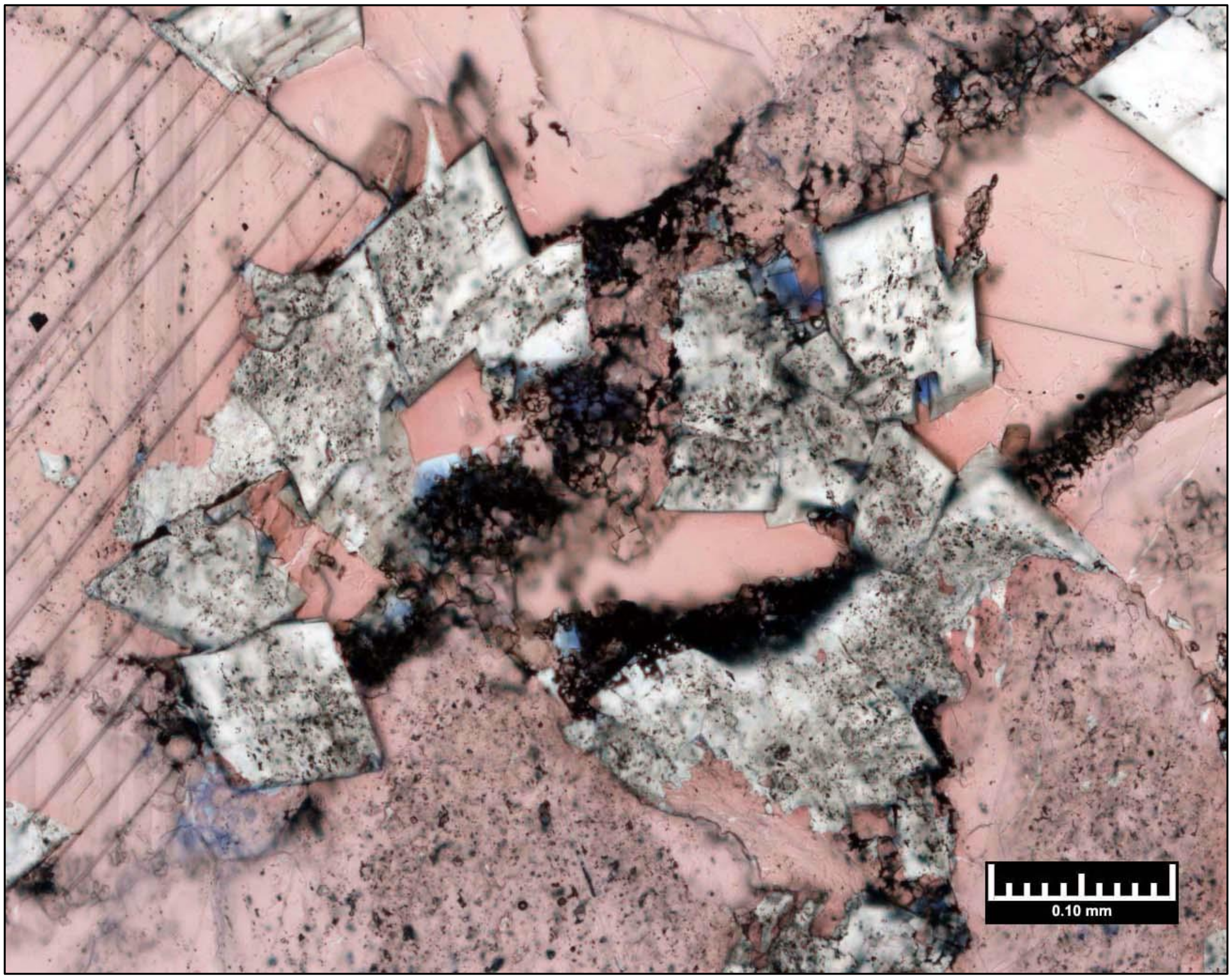


Figure 39. Sample 1-12R, 200x magnification photomicrograph. The high magnification photomicrograph provides a magnified view of well formed euhedral dolomite rhombs. Note the dark organic material comprising the stylolitic seam. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.

SUMMARY OF ROTARY CORE ANALYSES RESULTS
Vacuum Dried at 180F Net Confining Stress: 2000 psi

Well: Evans No. 6
Haskell County, OK

Sample Number	Sample Depth, ft	Permeability, millidarcys		Porocity %		Grain Density, gm/cc	Lithological Summary
		To Air	Klinkenberb	Ambient	NCS		
1-4R	6176	0.285	0.192	5.1	5.0	2.75	Ls spry sdol
1-5R	6180	0.050	0.026	5.4	5.2	2.77	Ls
1-6R	6204	0.012	0.0044	5.5	5.3	2.81	Dol svug sshlyl
1-7R	6208	0.856	0.645	7.7	7.6	2.81	Dol svug sshlyl
1-8R	6214	11.5	9.31	9.0	8.8	2.81	Dol svug sshly filled fractures
1-9R	6218	0.038	0.018	6.2	6.0	2.80	Dol svug sshly
1-10R	6222	0.045	0.022	2.3	2.2	2.78	Ls sdol
1-11R	6242	0.017	0.0071	4.4	4.2	2.81	Ls sdol spyr
1-12R	6260	0.0035	0.0009	2.1	2.0	2.73	Ls spyr
Average vlaues:		1.42	1.14	5.3	5.1	2.78	

Figure 40. Evans No. 6 summary of rotary core analyses results.

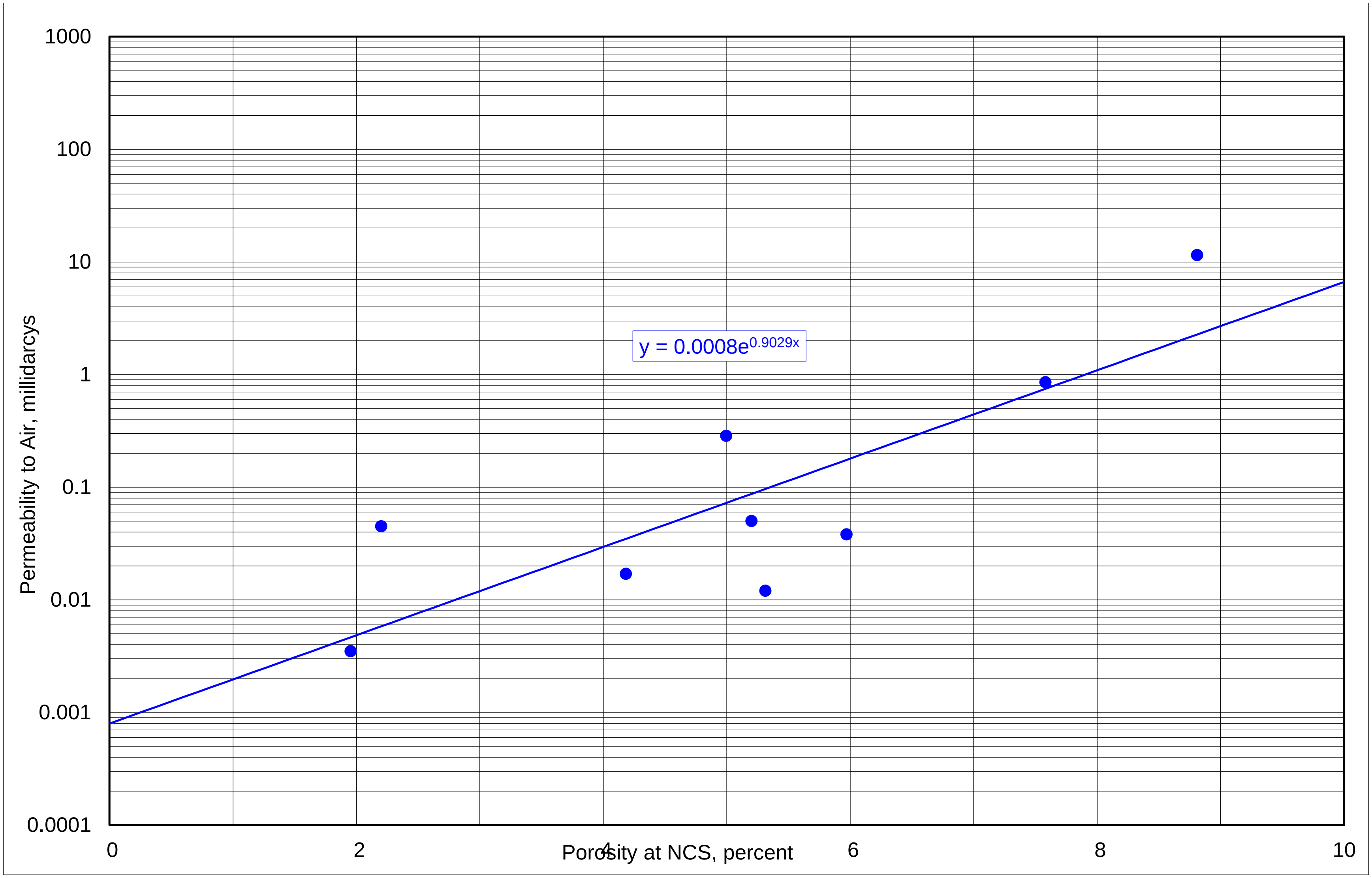


Figure 41. K$\boldsymbol{\theta}$ plot showing permeability versus porosity.

X-RAY DIFFRACTION
(WEIGHT %)

Well: **Evans No. 6**
Area: **Haskell County, OK**
Sample Type: **Rotary Sidewall Core**

Sample	Sample	CLAYS				CARBONATES			OTHER MINERALS						TOTALS		
Number	Depth (ft)	Chlorite	Kaolinite	Illite	Mx I/S*	Calcite[1]	Dol/Ank	Siderite	Quartz	K-spar	Plag.	Pyrite	Zeolite	Barite	Clays	Carb.	Other
1-1R	6116.0	2	1	12	2	0	3	Tr	70	1	2	7	0	0	17	3	80
1-2R	6140.0	4	1	24	4	0	4	Tr	36	1	4	22	0	0	33	4	63
1-3R	6150.0	2	1	16	3	0	4	Tr	59	1	4	10	0	0	22	4	74
	AVERAGE	3	1	17	3	0	4	Tr	55	1	3	13	0	0	24	4	72

* Ordered interstratified mixed-layer illite/smectite; Approximately 10-15% expandable interlayers
[1] May include the Fe-rich variety

Figure 42. X-ray diffraction results of the Evans No.6 well

SHALE ROCK PROPERTIES

SUMMARY OF ROUTINE CRUSHED CORE ANALYSES RESULTS

As-Received and Vacuum Dried at 180°F

Evans No.6											
		A-R	A-R	A-R	A-R	A-R	A-R	A-R	Dry	Dry	Dry
	Sample	Bulk	Grain	Water	Oil	Gas	Gas Filled	Press Decay	Bulk	Grain	Helium
Sample	Depth ft	Density gm/cc	Density gms/cc	Saturation % PV	Saturation	Saturation	Porosity	Permeability	Density	Density	Porosity
ID					% of PV	% of PV	% of BV	md	gm/cc	gm/cc	% of BV
1-2R	6140	2.65	2.67	60.0	0.0	40.0	1.1	6.04E-05	2.63	2.70	2.7
1-3R	6150	2.60	2.64	37.1	0.0	62.9	1.3	8.48E-05	2.59	2.65	2.1
	Average values:	2.63	2.65	48.6	0.0	51.4	1.2	7.26E-05	2.61	2.68	2.4

As-received bulk volumes and bulk densities were determined on intact bulk sample material. The bulk material was crushed and all other analysis reported herein were conducted on the crushed material.

Figure 43. Evans No. 6 summary of routine crushed shale core analysis results.

Shell 1 Western Western Coal & Mining Company

The Shell 1 Western Coal & Mining Company well is located in the SE $\frac{1}{4}$ sec. 36, T.7 N., R. 32 W., Sebastian County, Arkansas. Haley and Frezon (1965) first described this well core. Amsden (1980) later studied the core in greater detail. At this time, Amsden had 28 thin sections prepared and 16 core specimens from the Hunton and Upper Sylvan were analyzed in the chemical laboratory of the Oklahoma Geological Survey (Figure 45). Several thin sections were evaluated for this report, as was the core, which is stored at the Arkansas Geological Survey in Little Rock, Arkansas. Figure 44 is a core log with lithological descriptions created the cored intervals and thin sections.

The Shell 1 Western Coal and Mining Company well was drilled to a total death of 10,921 feet, and penetrated the Upper Cambrian Arbuckle Formation. The Hunton Group has a thickness of 149 feet in this well. Uppermost Hunton stratum is predominantly chert, with varying amounts of sub angular detrital quartz. Detrital grains range in size from less than 0.1 mm two over 1 mm in size. These beds are assigned to the Penters Chert (Sallisaw Formation). Here the Penters has a thickness of 40 feet thick. All of the Hunton beds below the Penters Chert are assigned to the Chimneyhill Subgroup. The Penters Chert is underlined by crystalline and calcitic dolomites that contain little to no chert. The upper 30 feet of the Chimneyhill Subgroup include small amounts of fine subangular detrital quartz and occasional quartz veins that may suggest infiltration along solution cavities (Amsden, 1980). The chemical analysis conducted by Amsen (1980) suggests that the basal 15 feet (7944'-7959') of the Hunton is almost entirely crystalline dolomite with little insoluble detritus. Also present is a 2-foot interval of dolomitic crinoidal limestone (7953-7954 feet). This interval ranges as high as 41.18% $MgCO_3$, averaging 34.24% $MgCO_3$. Hydrochloric acid insolubles are low throughout, with an average of 0.80%

The crystalline dolomites have considerably less visual porosity. Amsden (1980) credits some of these pores to the dissolution of crinoid plates. He suggested that the entire Chimneyhill Subgroup in this well is largely heavily dolomitized crinoidal limestone. Some of the cavities visible in the thin sections show a linear form, suggesting solution movement along fractures.

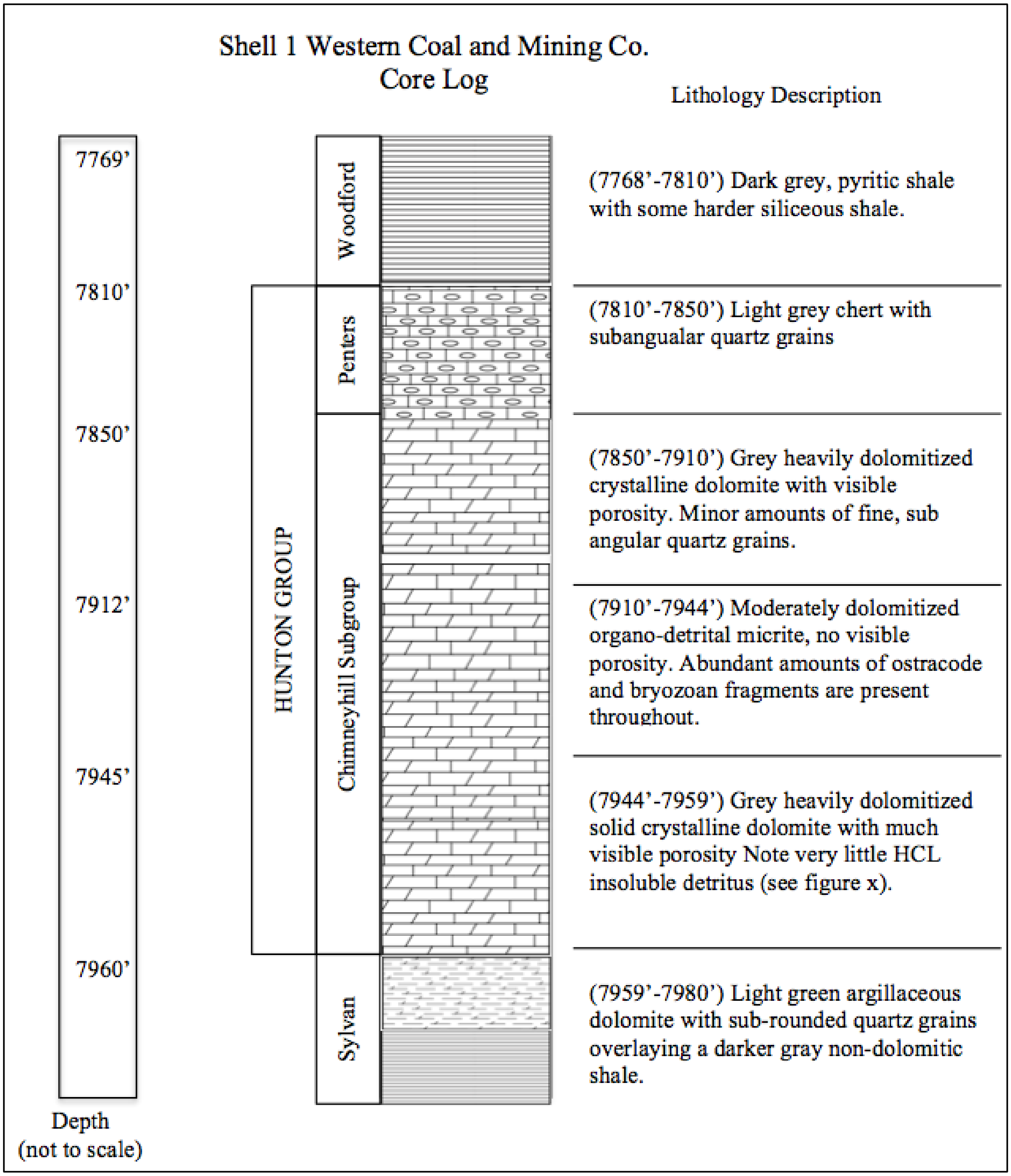


Figure 44. Lithologic diagram of core from Shell 1 Western Coal and Mining Company.

SHELL 1 WESTERN COAL & MINING COMPANY CORE SAMPLE ANYLSIS						
Depth (ft)	$CaCO_3$ %	$MgCO_3$ %	Insoluble Residue	Recovery	Mn (ppm)	Sr (ppm)
Chimneyhill Subgroup						
7944	59.32	39.02	0.82	99.16	198	100
7945	60.01	39.50	0.565	100.07	195	100
7948B	62.32	35.57	0.50	98.39	208	100
7948C	58.49	40.94	0.50	99.93	223	100
7950	61.30	36.41	0.52	98.23	228	100
7952A	66.14	31.77	0.44	98.35	250	112
7952B	56.65	41.18	1.16	98.99	238	75
7952C	59.66	37.80	1.04	98.50	235	62
7954A	86.81	11.28	0.48	98.57	120	88
7954B	83.12	15.99	0.52	99.63	145	112
7955	60.72	37.91	0.92	99.55	215	112
7957	58.92	39.40	1.08	99.40	245	125
7958B	58.27	38.97	2.60	99.84	358	162
7958	62.56	36.38	1.69	100.63	265	112
Average		34.44	.092			
Sylvan (Cason)						
7959	39.71	27.34	31.77	98.82	1100	125
7964	27.99	19.22	51.81	99.02	938	112

Figure 45. Chemical analysis of Shell 1Western Coal and Mining Company, as prepared by the chemical laboratory of the Oklahoma Geological Survey

Farmers Flag

The Humble 1 Farmers Flag Unit is located in the SE $\frac{1}{4}$ sec. 3, T.8 N., R. 23 E., Le Flore County, Oklahoma. This well was drilled in 1964 and no Hunton production has been reported. The Hunton Group is approximately 92 feet thick in the Farmers Flag well and range from a depth of 6348’ to 6440’. This section of Hunton strata has been correlated to the Chimneyhill Subgroup. The cored section and thin sections were evaluated and used to construct a core log (Figure 47). The cored interval was analyzed by David Foster in the Oklahoma geological survey chemical laboratory and has an average of 14.54 % $MgCO_3$. The upper 12 feet of Hunton stratum is the most heavily dolomitized portion in the well. As shown in Figure 46, the upper 12 feet of Hunton contains 27.40% $MgCO_3$.

Core Descriptions

The upper 12 feet, 6348'-6360, is a heavily dolomitized organo-detrital limestone and grades into a crystalline dolomite. Crinoid fragments account for the majority of the organic material and the fossils retain their micro-texture however, some have been replaced by calcite. There is very little visible porosity in this interval and it contains very little detrital quartz. In this section, hydrochloric acid insoluble averages 1.99%.

The next interval, taken from a depth of 6360'-6382', is a light gray organo-detrital micrite. This micrite is weakly to moderately dolomitized. The dolomite crystals are sparsely scattered throughout the matrix. Crinoidal fragments are the most abundant fossils in this interval. Other shell fragments present include those of brachiopods, ostracodes and bryozoans. In this section, hydrochloric acid insoluble averages 0.56%.

From 6382'-6396' is a heavily dolomitized organo-detrital limestone. This interval has an average $MgCO_3$ content of 13.62%. The matrix contains some dolomite and fossilized crinoid fragments. No detrital quartz was observed; average hydrochloric acid insoluble is 0.56%.

Samples were only available from a depth of 6396'-6440'. The Hunton at this depth is a moderately to heavily dolomitized pink crinoidal micrite. There is little to no visible porosity in this interval.

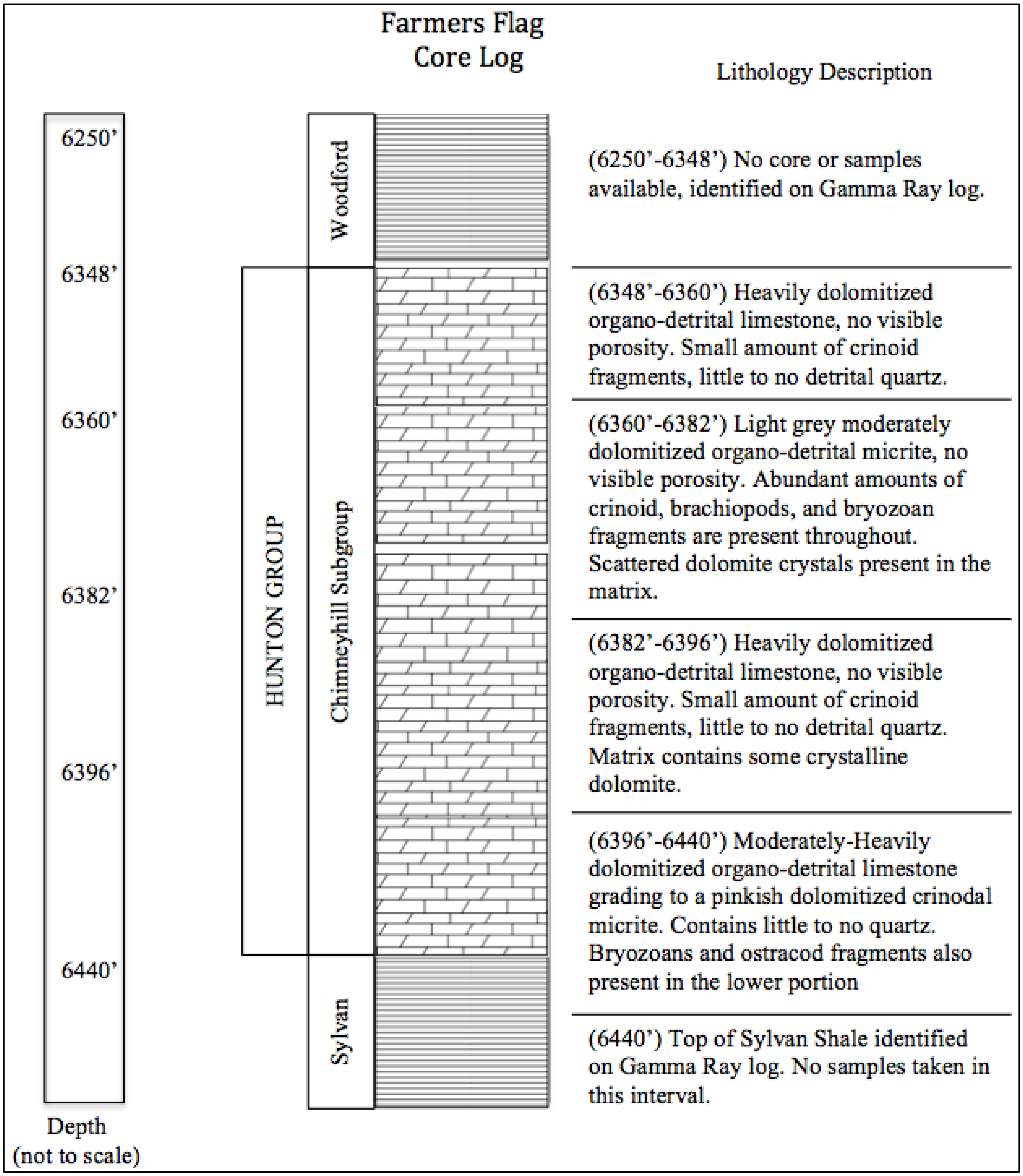


Figure 46. Lithologic diagram of core from Humble 1 Farmers Flag well.

Humble 1 Farmers Flag Core				
Percentage of Total Rock				
Interval (ft)	$CaCO_3$ %	$MgCO_3$ %	Insoluble Residue	Recovery
6348-6360	71.60	27.40	1.99	100.99
6360-6370	91.61	8.43	0.67	100.71
6370-6382	92.24	7.84	0.44	100.52
6382-6396	85.83	13.83	0.51	99.96
Weighted Average	85.08	14.54	0.90	

Figure 47. Lab analysis results of Humble 1 Farmers Flag Unit, as prepared by David Foster, chemical laboratory, Oklahoma geological survey.

CONCLUSION

Due to the major uplifts during and after the deposition of the Hunton Group, variations in Hunton thickness exist throughout the study area. As shown on the isopach map, Figure 14, the Hunton stratum is thickest in the northern part of the study area and thins towards the South were it is eventually nonexistent. The Woodford is thicker in the southern part of the study area and thins towards the north. The regional thickening of the Woodford is consistent with sedimentary patterns associated with the formation of sedimentary basins (Amsden, 1980). The local inverse relationship between the Woodford and Hunton is due to the filling of pre-Woodford surfaces

The petrographic analysis of the thin sections created from the Evans No. 6 well revealed that porosity exists in the form of intercrystalline and moldic porosity. The presence of trace amounts of gypsum supports the penecontemporaneous hypersaline dolomitization model, but overall the samples lack sufficient amounts of anhydrite cement and the dolomite crystals are euhedral with dark centers, characteristic of dolomites formed by a mixed-water mechanism (Al-Shaieb, 2000).

The deposition and dolomitization of the study area likely took place in the intertidal zones of Facies II nearing Facies III as shown in Figures 9 and 12. This interpretation is supported by the absence of algal sedimentary structures that are typically present in Facies I and the lack of silty dolomitic mudstones associated with the subtidal environments of Facies III. The irregular occurrence of porosity throughout the area is related to burrowing and the redistribution of finer particles. This redistribution enhanced dissolution by allowing the movement of acidic fluids through the rock (Al-Shaieb and other, 1993). Another factor hindering the existence of porosity is the later cementation by sparry calcite. It is evident in the thin sections that calcite was again precipitated after dolomitization. A later cementation by sparry calcite has filled a significant portion of solution-enlarged molds, reducing the overall amount of porosity in the study area. Another obvious, yet important observation is that hydrocarbon production in the area is not only related to porosity and permeability, but it also is dependent upon the actual presence of gas. Some of the dry holes drilled in the study did have significant amounts of porosity, but hydrocarbons simply were nonexistent.

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APPENDICE

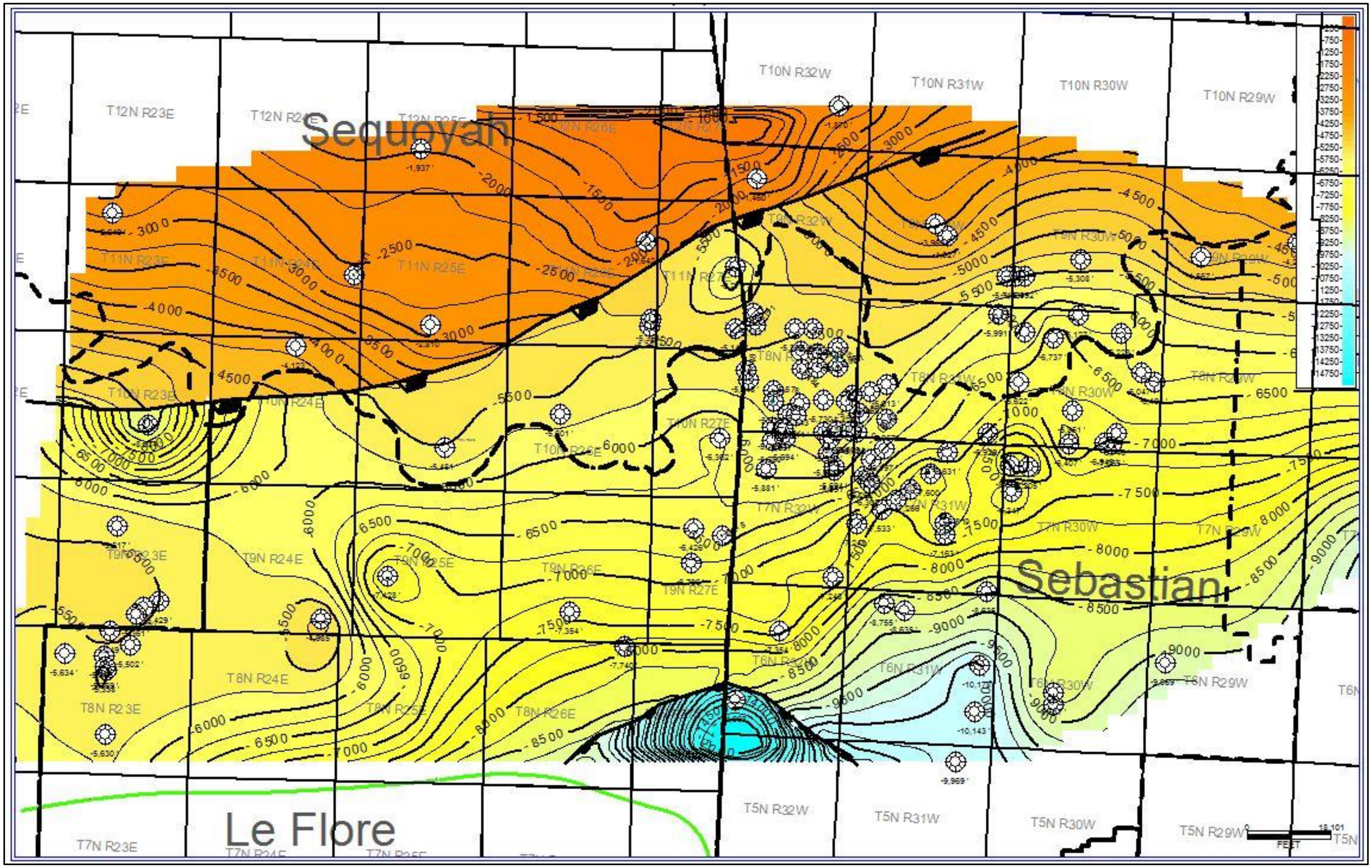

Figure 48. Structure map depicting the top of the Hunton Group and two large normal faults. Contour interval is 250 ft.

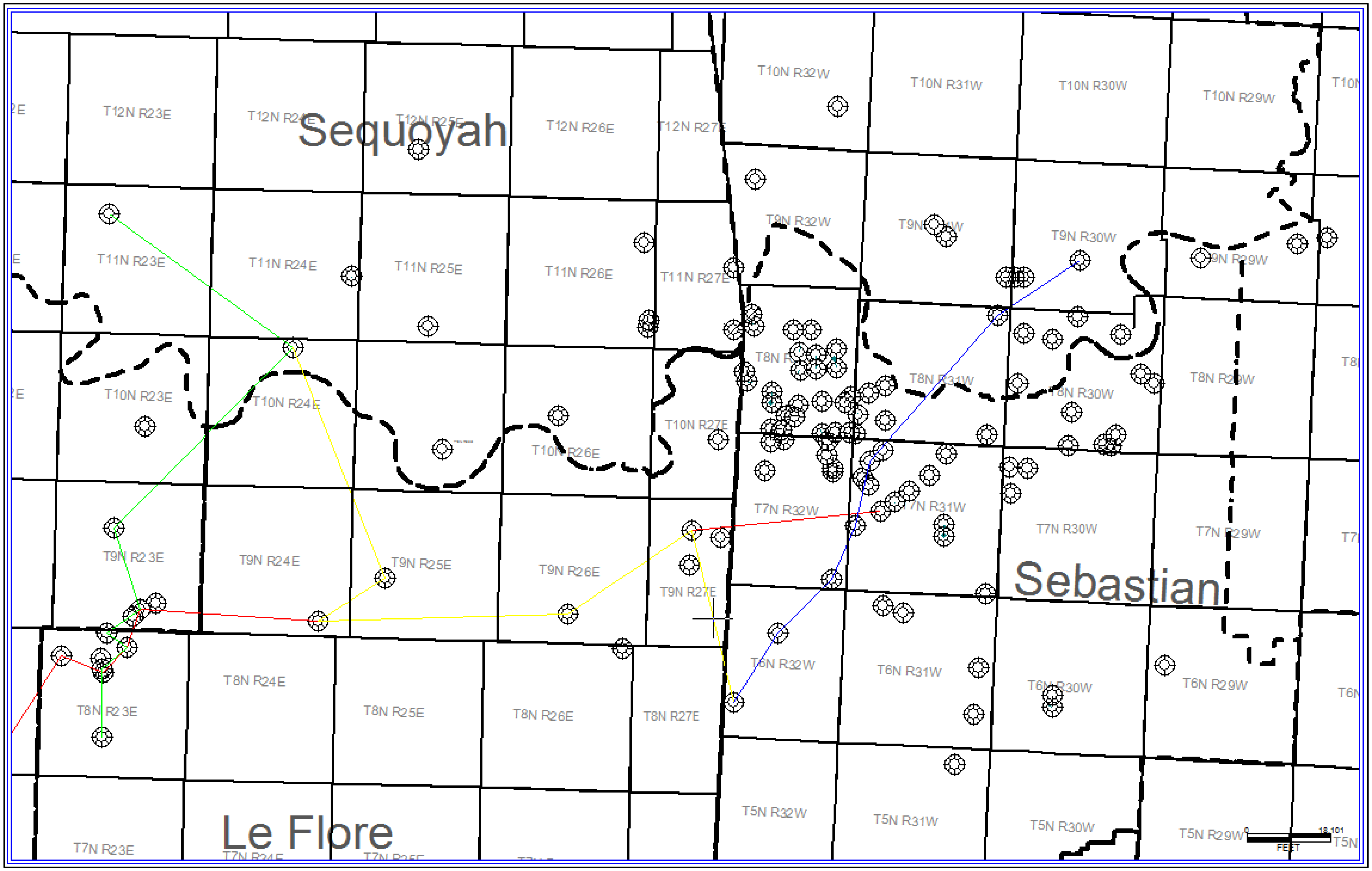

Figure 49. Index to stratigraphic cross-sections.

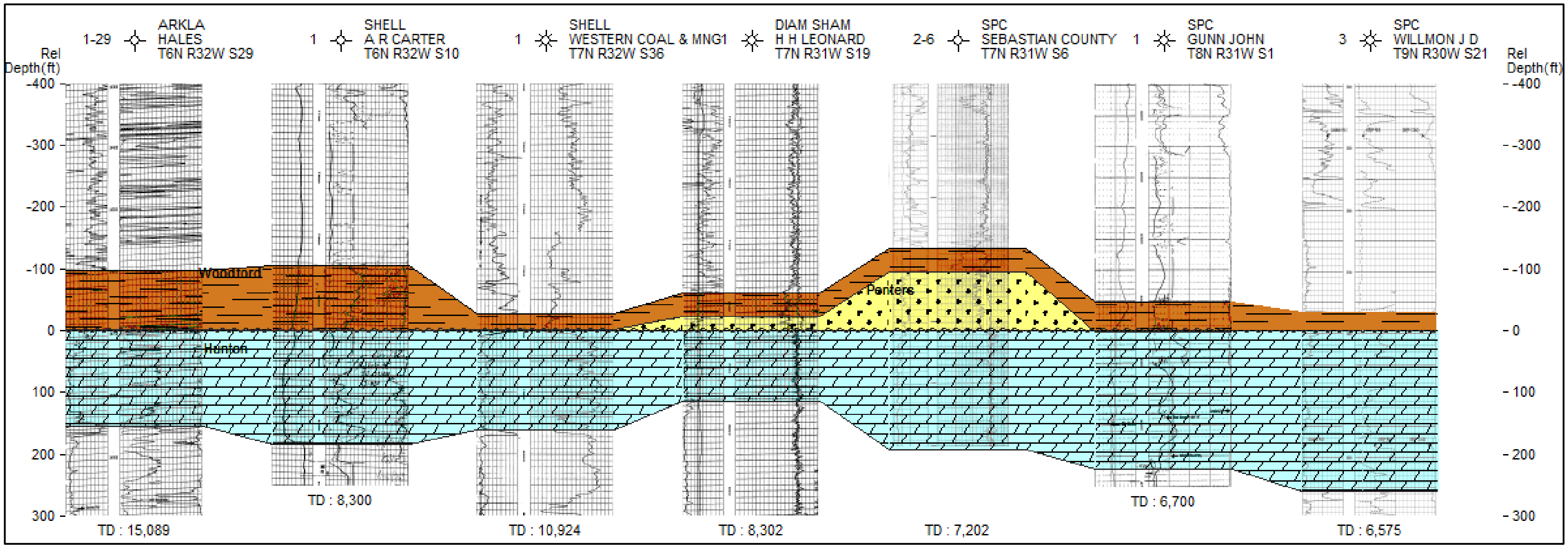

Figure 50. North-south stratigraphic cross-section depicted by the blue section on cross-section index.

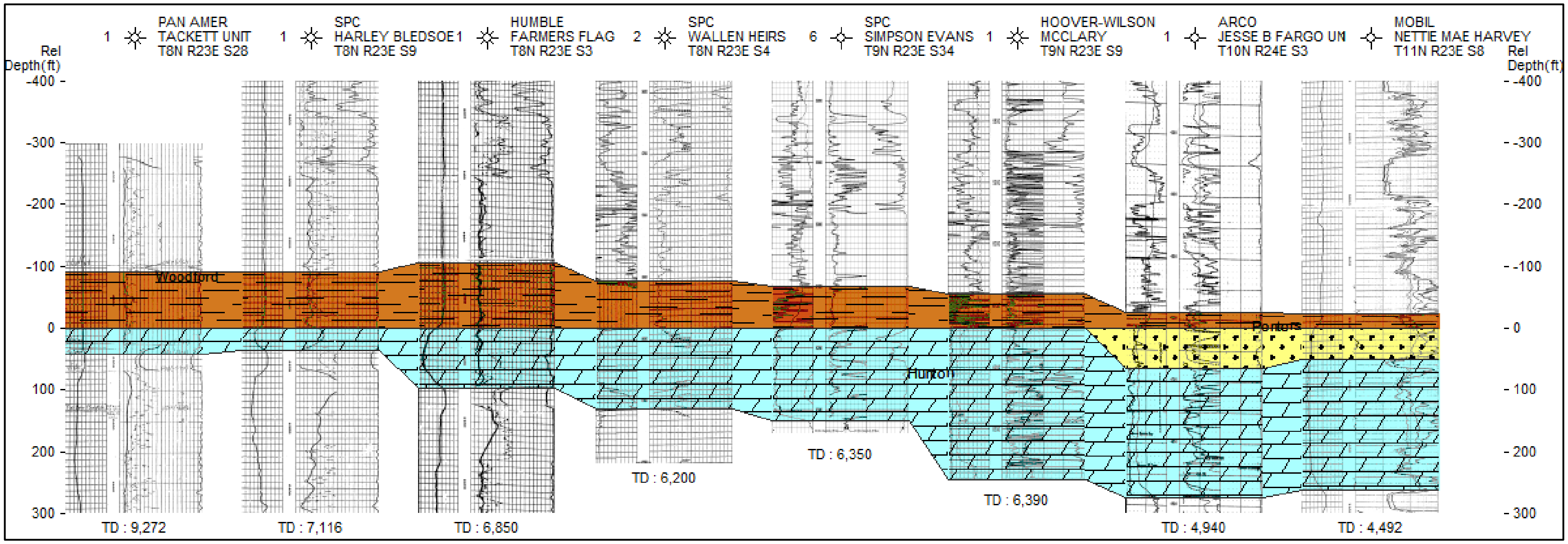

Figure 51. North-south stratigraphic cross-section depicted by the green section on cross-section index.

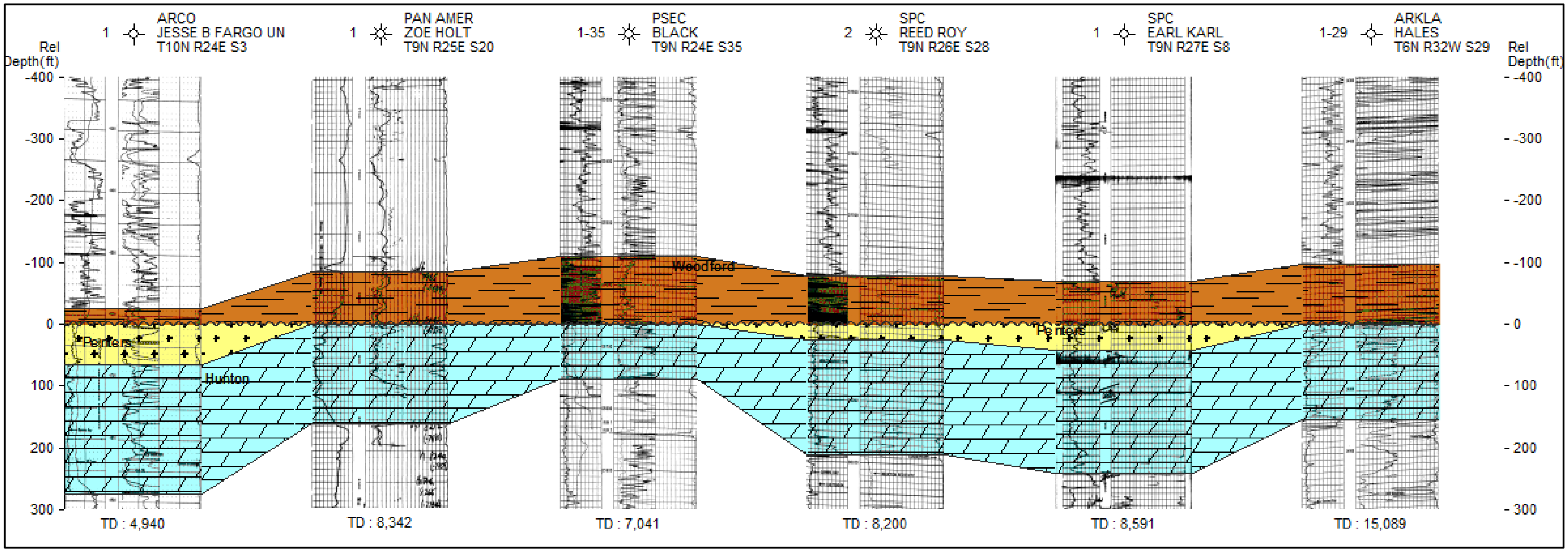

Figure 52. North-south stratigraphic cross-section depicted by the yellow section on cross-section index.

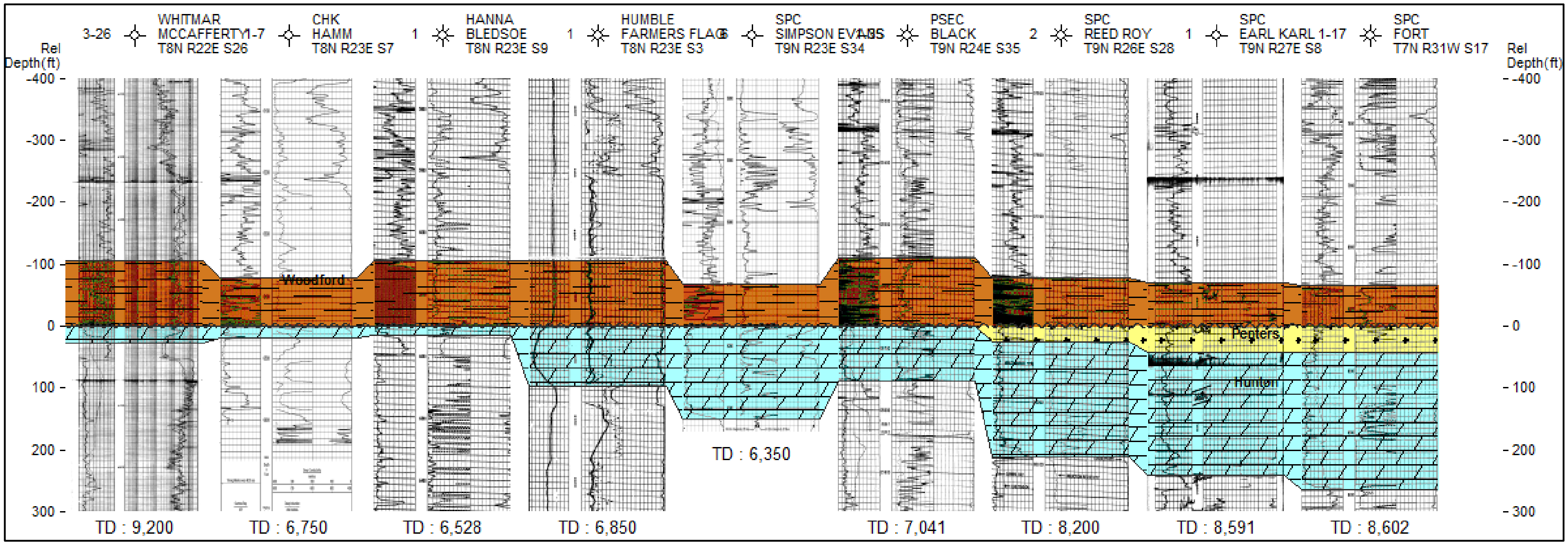

Figure 53. East-west stratigraphic cross-section depicted by the red section on cross-section index.

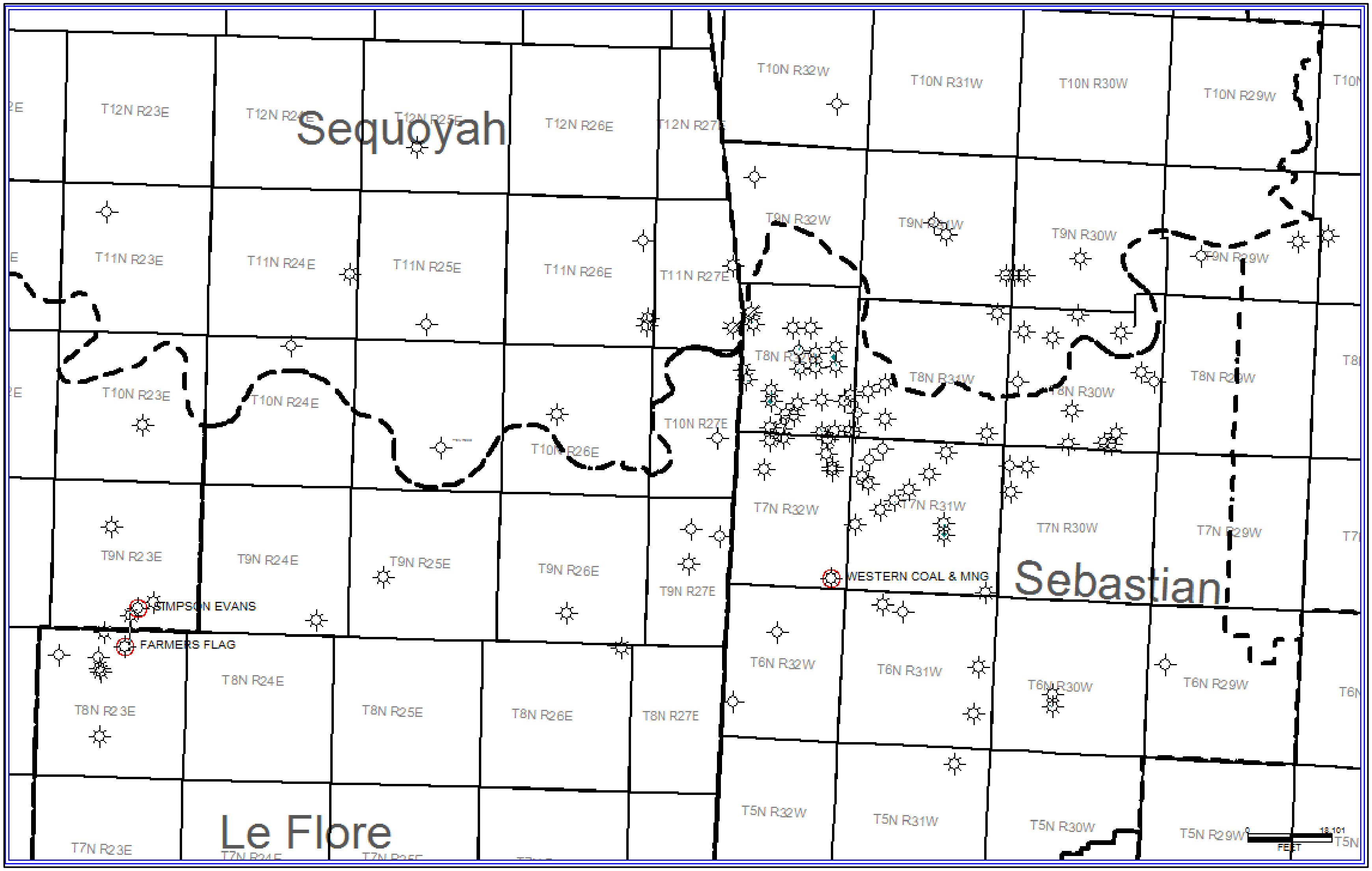

Figure 54. Map view of study area highlighting cored wells.

UWI	Well Name	Well	Operator	Sec	T	Range	TD	Top Hunton	Isopach Woodford	Isopach Hunton	Isopach Penters
3033002330000	INGRAM	1	SPC	2	8N	30W	8020	6670	45	329	67
3033100220000	MILDRED ALEXANDER	1	SPC	4	8N	30W	6988	6560	32	300	48
3033100300000	CLYMA	1-16	ARKLA	16	9N	31W	5400	4442	21	269	61
3033100320000	LINDSEY HATCHETT	2	SPC	30	9N	30W	6592	5960	8	276	8
3033100360000	NANCY ORR	1	DIAM	8	9N	32W	3100	2010	30	246	64
3033102070000	HOUSE HAROLD	2	SPC	22	9N	31W	4958	4536	21	258	57
3033102490000	ARNOLD JAMES	6	SPC	8	8N	30W	7550	7160	32	323	65
3033103090000	BRINEGAR UNIT	2-25	ANADARK	25	9N	31W	6290	5866	24	287	65
3033103350000	HATCHETT LINDSEY	7	SPC	30	9N	30W	7205	5938	17	222	39
3033302250000	GUNN JOHN	1	SPC	1	8N	31W	6700	6449	49	221	
3033300350000	HOWARD GENTRY	1	SPC	19	8N	30W	7660	7040	22	363	68
3033003020000	DENT VIVIAN C	1	SPC	6	8N	30W	7180	6330		310	61
3047102450000	ADAMS	1-21	SPC	21	7N	28W	11262	9930	55	242	16
3047600310000	ARK VALLEY TR CO	1	XTO	19	9N	28W	8638	5080	37	226	37
3131000010000	BUELL RANCH	3	SPC	9	7N	32W	6770	6415	37	317	
3131000070000	WESTERN COAL & MNG	1	SHELL	36	7N	32W	10924	7799	28	160	51
3131000450000	RANDOLPH SENGEL	1	SPC	25	8N	32W	6310	5925	42	306	66
3131000810000	SKINNER	1	SHELL	4	6N	31W	9751	9330	34	169	
3131000930000	A R CARTER	1	SHELL	10	6N	32W	8300	8050	106	184	

3131002090000	BERTHA WILLIAMS	1	SPC	30	8N	31W	6361	5960	40	297	
3131100070000	CECIL M JONES	1	SPC	35	8N	30W	7600	7280	77	167	53
3131100340000	FORT CHAFFEE	2	SPC	7	7N	31W	7343	6898	48	260	
3131100400000	H H LEONARD	1	DIAM SHAM	19	7N	31W	8302	7816	38	328	24
3131100410000	FORT CHAFFEE	1	SPC	5	7N	31W	7053	6760	61	228	70
3131100750000	HRDSCRBBLE	2	SPC	26	8N	32W	6584	6270	40	302	
3131100810000	U S A	1-36	ARKLA	36	8N	31W	7766	7368	40	195	21
3131100890000	U S A	1-2	ARKLA	6	7N	30W	9625	9095	41	248	32
3131100980000	BELL	1-25	QUESTAR	25	6N	31W	12063	10891	77	138	
3131101320000	MILL CREEK	1	HANNA	4	7N	32W	6527	6185	43	255	
3131101350000	HOLLEMAN	1	ARKLA	5	6N	31W	9673	9368	59	160	56
3131101860000	KRADEL	1-32	TOWNER	32	8N	31W	6850	6480	46	242	101
3131102010000	AIRPORT 81	1	HANNA	34	8N	32W	6618	6170	30	250	
3131102080000	HALES	1-29	ARKLA	29	6N	32W	15089	14691	96	154	
3131102170000	KOENIG	1	TXO	20	8N	31W	6451	6050	28	297	78
3131102220000	SHALE PIT	2	SPC	3	7N	32W	6708	6225	34	288	84
3131102250000	INEZ INGRAHAM	3-24	SPC	24	8N	30W	7177	6650	52	323	19
3131102390000	FORT CHAFFEE	2-12	TOWNER	12	7N	32W	6770	6480	60	235	73
3131102450000	DALE A SAWYER	1	FOREST	10	8N	32W	6733	5857	31	293	73
3131102470000	CAMP CHAFFEE	2-1	SPC	3	7N	31W	7646	7079	31	273	71
3131102600000	KELLEY /A/	1	CHK	27	8N	32W	6750	6255	33	276	83
3131102610000	PEERLESS COAL	1-3	SPC	13	6N	31W	12237	10772	87	207	

3131102640000	USA	22-1	GETTY	22	7N	31W	9211	7674	58	248	92
3131102710000	SEBASTIAN COUNTY	2-6	SPC	6	7N	31W	7202	6813	132	193	
3131102760000	PORTER D	1	CHK	28	8N	32W	6727	6190	34	301	
3131102830000	PORT AUTHORITY	1	CHK	20	8N	32W	6620	6190	17	335	
3131102860000	CHURCH `B`	B-1	CHK	33	8N	32W	6750	6305	28	265	
3131103010000	AIRPORT 83	1	HANNA	34	8N	32W	6550	6168	27	287	
3131103050000	FT CHAFFEE	1	EXXON	18	6N	29W	12755	9758	70	253	16
3131103060000	CENTRAL MALL	1	FOREST	23	8N	32W	7500	6168	33	283	
3131103110000	FT SMITH	1	CHK	8	8N	32W	6300	5880	23	303	
3131103190000	O`NEAL	1-14	FOREST	14	8N	32W	7060	6234	28	274	81
3131103310000	ROGERS KAY	3-5	SPC	8	8N	32W	6025	5630	18	258	
3131103340000	VICK	1-11	FOREST	11	8N	32W	6309	5963	25	296	81
3131103630000	PARK AVENUE	1	TXO	15	8N	32W	6998	6535	32	280	73
3131103800000	FORT CHAFFEE	3-7	SPC	7	7N	31W	7270	6858	17	292	
3131104350000	ACME BRICK	3	SONAT	22	8N	32W	7105	6359	40	310	
3131104360000	FORT CHAFFEE	2-12	TERRA RES	12	7N	32W	6604	6205	44	248	
3131104730000	USA	3-6	REVERE	6	7N	30W	9975	8650	37	371	
3131104760000	MUNICIPAL AIRPORT	5	SPC	36	8N	32W	7600	6080	32	323	83
3131104920000	YOUNG CHARLES	2-24	SPC	13	8N	32W	7370	6730	29	266	69
3131104930000	PIGG DORA	2	SPC	31	8N	31W	6540	6114	45	320	
3131105460000	BIEKER GEORGE	3	SPC	2	7N	32W	6592	6109	41	324	
3131105520000	ALLEN M F F	4	SPC	30	8N	31W	6497	6040	44	302	75
3131105860000	FORT	1-17	SPC	17	7N	31W	8602	8134	66	261	43
3131105910000	USA	2-7	SEAGULL	7	7N	30W	9020	6840	59	239	95

			MS								
3131106170000	AIRPORT `94	1	HANNA	34	8N	32W	6610	6178	42	276	80
3131106520000	JONES	3	SPC	35	8N	30W	7858	7593	63	141	35
3131106790000	PATTERSON E A	2	SPC	34	8N	30W	7830	7410	14	191	15
3131107100000	SENGEL	2	SPC	25	8N	32W	7315	5936	24	304	
3131107270000	RESERVE	1-36	SPC	36	7N	31W	9745	9340	101	173	60
3131107340000	AIRPORT	1-35	SPC	35	8N	32W	6700	6214	39	304	101
3131107680000	THOMAS WAYNE	4	SPC	33	8N	30W	7376	6893	64	156	40
3131107710000	GILL	5	SPRING RES	13	8N	30W	7100	6516	68	216	66
3131107880000	MUNICIPAL AIRPORT	7-36	SPC	36	8N	32W	6595	6098	32	330	
3131108070000	BIEKER GEORGE	4	SPC	2	7N	32W	6610	6167	57	255	
3131300350000	BRYANT ANNIE V	1	SPC	28	8N	30W	8345	7360	57	317	47
3506120500000	ELZA HARRISON	1-22	BROCK HYDROCR BNS INC	22	10N	23E	9512	9395	27		23
3506120887000	MCCAFFERTY	3-26	WHITMAR	26	8N	22E	9200	6572	106	28	
3506121115000		3-26		26	9N	23E	6305	6248	68	184	
3506121161000	MCCLARY	1	HOOVER-WILSON	9	9N	23E	6390	6135	55	244	
3507900035000	ZOE HOLT	1	PAN AMER	20	9N	25E	8342	8045	84	161	
3507900036000	TACKETT UNIT	1	PAN AMER	28	8N	23E	9272	6247	91	43	
3507920006000	ARKANSAS VALLEY FAR	1	SUN OIL COMPANY	21	10N	27E	7233	6813	27	314	86
3507920172000	EARL KARL	1	SPC	8	9N	27E	8591	6935	69	242	42

3507920611000	BLEDSOE HARLEY	2	SPC	9	8N	23E	6430	6355	84	57	
3507920733000	BLEDSOE	1	HANNA	9	8N	23E	6528	6152	106	14	
3507920760000	BLACK	1-35	PSEC	35	9N	24E	7041	5663	110	88	
3507920780000	REED ROY	2	SPC	28	9N	26E	8200	7875	77	210	25
3507920905000	WALLEN HEIRS	2	SPC	4	8N	23E	6200	5980	76	130	
3507960013000	FARMERS FLAG	1	HUMBLE	3	8N	23E	6850	6346	106	96	
3507960017000	HARLEY BLEDSOE	1	SPC	9	8N	23E	7116	6140	90	37	
3513520106000	JESSE B FARGO UN	1	ARCO	3	10N	24E	4940	4612	25	275	66
3513520161000	COAN E E	3	SPC	16	10N	26E	6652	6078	39	292	56
3513520168000	PATES FARMS	1	OXLEY	25	11N	26E	6812	5808	26	290	28
3513520187000	MIRIAM	1	OXLEY	36	11N	26E	7800	5825	26	288	81
3513520198000	BROOKS	1	OXLEY	12	11N	26E	2632	2263	24	317	78
3513520223000	LOWREY	1-33	SWESTER N	33	11N	25E	3685	3320	37	322	99
3513520281000	REDLAND RANCH	12	SPC	27	10N	25E	6529	6127	41	289	68
3513520081000	CATES	1	WYTEX	15	11N	27E	7125	6720	18	289	71
3513520236000	ARKANSAS VALLEY FAR	3	SPC	34	11N	27E	6051	5588	23	315	78
3506121243000	SIMPSON EVANS	4	SPC	34	9N	23E	6638	6119	78	110	
3131109220000	MARTIN FRED	7-29	CROSS TIMBERS	29	9N	29W	5600	4952	13	307	58
3131109720000	CUSTER	1-9	SPC	9	7N	30W	8620	7800	40	282	90
3513520138000	FEDERAL LAND BANK	1	HUNT	28	12N	25E	5044	2615	26	297	71
3513530002000	NETTIE MAE	1	MOBIL	8	11N	23E	4492	3209	22	262	51

3033101130000	FITE	1-26	CARLYLE	26	10N	32W	3150	2740	19	300	66
3131105080000	THOMPSON	1X	COASTAL	2	5N	31W	13400	10772	122	263	
3507921564000	HAMM	1-7	CHK	7	8N	23E	6750	6447	78	18	
3131110820000	PORTER	D-4	CHK	28	8N	32W	7482	6682		310	
3131111130000	PORT AUTHORITY	3	CHK	20	8N	32W	7290	6202	27	319	
3131112050000	SYNOGROUN D	16	SPC		S	W	10395	9628		226	
3131112500000	OLD GLORY	3-10	SPC	10	7N	31W	8446	8105	67	222	
3131112040000	FORT	3-17	SPC	17	7N	31W	8270	7876	66	237	54
3513520371000	WILDHORSE	2-24	SPC	24	11N	24E	3650	3246	26	314	99
3507921691000	CASEY	1-1	SEDNA	1	8N	26E	8800	8432	94	174	
3131111960000	MURPHY	9-21	XTO	21	6N	30W	11200	9358	82	216	13
3131112110000	USA	1-22	SPC	22	7N	31W	8225	7900	63	224	82
3033105920000	WILLMON J D	3	SPC	21	9N	30W	6575	5795	28	259	41
3047113460000	MORRIS LAIN	5-25	XTO	24	9N	29W	5513	5078	46	205	34
3506122318000	EVANS	6	SPC	34	9N	23E	6350	6168	67	149	
3507922035000	HOOVER CHARLES	5-17	SPC	17	9N	27E	7734	7308	16	224	38
3131114020000	FREE FERRY ESTATES	5	SPC	13	S	W	6443	6090	32	226	88
3507922077000	PRYOR	1-9	SPC	9	9N	27E	7121	6720	54	275	

Figure 55. List of wells included in study area

UWI	Well Name	Well	Operator	Sec	T	Range	TD	BCF PENTERS Arkansas	BCF HUNTON Arkansas	BCF HUNTON Oklahoma
3033103090000	BRINEGAR UNIT	2-25	ANADARK	25	9N	31W	6290	0.842	0.842	

3033302250000	GUNN JOHN	1	SPC	1	8N	31W	6700			
3131000010000	BUELL RANCH	3	SPC	9	7N	32W	6770			
3131000070000	WESTERN COAL & MNG	1	SHELL	36	7N	32W	10924		2.44	
3131000450000	RANDOLPH SENGEL	1	SPC	25	8N	32W	6310		6.538	
3131000810000	SKINNER	1	SHELL	4	6N	31W	9751			
3131000930000	A R CARTER	1	SHELL	10	6N	32W	8300			
3131002090000	BERTHA WILLIAMS	1	SPC	30	8N	31W	6361	6.873	14.436	
3131100750000	HRDSCRBBLE	2	SPC	26	8N	32W	6584			
3131101320000	MILL CREEK	1	HANNA	4	7N	32W	6527	0.488		
3131102010000	AIRPORT 81	1	HANNA	34	8N	32W	6618	1.218		
3131102220000	SHALE PIT	2	SPC	3	7N	32W	6708	0.001		
3131102600000	KELLEY /A/	1	CHK	27	8N	32W	6750	5.771	5.771	
3131102640000	USA	22-1	GETTY	22	7N	31W	9211	2.7		
3131102760000	PORTER D	1	CHK	28	8N	32W	6727	0.447		
3131103010000	AIRPORT 83	1	HANNA	34	8N	32W	6550	0.435	0.435	
3131103060000	CENTRAL MALL	1	FOREST	23	8N	32W	7500	5.25		
3131103110000	FT SMITH	1	CHK	8	8N	32W	6300	2.962		
3131103190000	O`NEAL	1-14	FOREST	14	8N	32W	7060	3.367		
3131103310000	ROGERS KAY	3-5	SPC	8	8N	32W	6025	0.088		
3131104350000	ACME BRICK	3	SONAT	22	8N	32W	7105	3.519	5.262	
3131104360000	FORT CHAFFEE	2-12	TERRA RES	12	7N	32W	6604		0.233	
3131104760000	MUNICIPAL AIRPORT	5	SPC	36	8N	32W	7600	0.01	0.01	
3131104930000	PIGG DORA	2	SPC	31	8N	31W	6540			
3131105910000	USA	2-7	SEAGULL MS	7	7N	30W	9020	4.1	4.1	
3131107100000	SENGEL	2	SPC	25	8N	32W	7315	0.337		
3131107340000	AIRPORT	7-35	SPC	35	8N	32W	6700	0.01	1.5	

3131107710000	GILL	5	SPRING RES	13	8N	30W	7100		0.004	
3131107880000	MUNICIPAL AIRPORT	7-36	SPC	36	8N	32W	6595		0.19	
3131108070000	BIEKER GEORGE	4	SPC	2	7N	32W	6610		0.783	
3131300350000	BRYANT ANNIE V	1	SPC	28	8N	30W	8345		0.002	
35061211150000		3-26		26	9N	23E	6305			0.093
35079000350000	ZOE HOLT	1	PAN AMER	20	9N	25E	8342			
35079207330000	BLEDSOE	1	HANNA	9	8N	23E	6528			0.01
35079209050000	WALLEN HEIRS	2	SPC	4	8N	23E	6200			0.969
35079600170000	HARLEY BLEDSOE	1	SPC	9	8N	23E	7116			2.625
35135201680000	PATES FARMS	1	OXLEY	25	11N	26E	6812			2.578
35135202360000	ARKANSAS VALLEY FAR	3	SPC	34	11N	27E	6051	2.6		
35061212430000	SIMPSON EVANS	4	SPC	34	9N	23E	6638			0.081
31311097200000	CUSTER	1-9	SPC	9	7N	30W	8620	1.49	0.001	
31311120400000	FORT	3-17	SPC	17	7N	31W	8270		0.752	
31311121100000	USA	1-22	SPC	22	7N	31W	8225	0.817	0.01	
30331059200000	WILLMON J D	3	SPC	21	9N	30W	6575		0.01	

Figure 56. List of hydrocarbon producing wells in study area.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6176 ft
Sample Number: 1-4R

Measured Porosity: 5.1%
Permeability (Klinkenberg): 0.192md
Grain Density: 2.75gm/cc

Lithology: Dolomitic Limestone
Sedimentary Fabric: Obscured by diagenesis; stylolitic seams; some crystal size-zoning

Dolo. Crystal Range: 0.05mm-0.35mm
Dolo. Crystal Size: 0.20mm avg.
Compaction: High (stylolitic seams)
Dolo. Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace pore-lining

Cement Types: Dolomite; calcite spar; Pyrite

Porosity Types: Intercrystalline; occurs within regions of partial dolomite infilling of molds and as dissolution variety associated with stylolites

Reservoir Quality: Poor to Fair; limited pore space

Magnification: A: 40X B: 200X

A) The survey photomicrograph is a low magnification view which displays a typical view of rock composition, which is dominated by calcite (red) with lesser dolomite (tan). Note the organic concentrations (opaque) defining the jagged stylolitic seam. Porosity (blue) is poorly developed overall.

B) The high magnification photomicrograph provides a magnified view of intercrystalline porosity, which are regions between dolomite rhombs. Note the dark organic material comprising the stylolitic seams. Calcite spar is also abundant in this limestone and exists as both a cement and as replaced allochems.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6180 ft
Sample Number: 1-5R

Measured Porosity: 5.4%
Permeability (Klinkenberg): 0.026md
Grain Density: 2.77gm/cc

Dolo. Crystal Range: 0.05mm-0.30mm
Dolo. Crystal Size: 0.20mm avg.
Compaction: High (stylolitic seams)
Dolo. Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace pore-lining

Cement Types: Pyrite; dolomite; calcite spar

Porosity Types: Intercrystalline; occurs within regions of partial dolomite infilling of molds and as dissolution variety associated with stylolites

Reservoir Quality: Poor to Fair; limited pore space

Magnification: A: 40X B: 200X

A) The survey photomicrograph is a low magnification view which displays a typical view of rock composition, which is dominated by calcite (red) with lesser dolomite (tan). Note the organic concentrations (opaque) defining the jagged stylolitic seam. Porosity (blue) is poorly developed, overall.

B) The high magnification photomicrograph provides a magnified view of porosity found in intercrystalline regions between dolomite rhombs. Note the dark centers of the well-formed dolomite crystals. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6204 ft
Sample Number: 1-6R

Measured Porosity: 5.5%
Permeability (Klinkenberg): 0.0044md
Grain Density: 2.81gm/cc

Dolo. Crystal Range: 0.05mm-0.35mm
Dolo. Crystal Size: 0.20mm avg.
Compaction: High (stylolitic seams)
Dolo. Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace pore-lining

Cement Types: Dolmite; calcite spar

Porosity Types: Intercrystalline; occurs within regions of partial dolomite infilling of molds and as dissolution variety associated with stylolites

Reservoir Quality: Fair; limited pore space

Magnification: A: 40X B: 200X

A) The survey photomicrograph is a low magnification view which displays a typical view of rock composition, which is dominated by dolomite (tan) with lesser calcite (red). Note the organic concentrations (opaque) and calcite filling the stylolitic seam. Porosity (blue) is poorly developed, overall, in this limestone.

B) The high magnification photomicrograph provides a magnified view of organic concentration and euhedral rhombohedra with dark centers. Porosity is found in intercrystalline regions between dolomite rhombs. Calcite spar is abundant as cement between dolomite rhombs.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6208 ft
Sample Number: 1-7R

Measured Porosity: 7.7%
Permeability (Klinkenberg): .645 md
Grain Density: 2.81gm/cc

Lithology: Dolostone
Sedimentary Fabric: Obscured by diagenesis; some crystal size-zoning; pre-stylolitic seams

Dolomite Crystal Range: 0.03mm-0.30mm
Dolomite Crystal Size: 0.15mm
Compaction: Moderate to High (pre-stylolitic seams)
Dolomite Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace (pore-lining)

Cement Types: Dolomite (abundant) as a replacement of rock groundmass; calcite spar (minor) fills vugs and molds; rare pore-filling gypsum

Porosity Types: Intercrystalline (both within regions of partial dolomite infilling of molds and true groundmass intercrystal pores); moldic pores are also common

Reservoir Quality: Fair to Good; decent interconnection of pores and moderate overall porosity

Magnification: A: 40X B: 200X

A) The low magnification survey photomicrograph features a slightly calcitic dolostone. Dolomite (tan) is dominant; calcite spar (stained red) mainly fills molds. Moldic areas not infilled retain pore space (blue) Note the organic concentrations (opaque) defining the jagged stylolitic seam.

B) This photomicrograph provides a magnified view of the intercrystalline porosity between dolomite rhombs and dark organic material along the stylolitic seam. Note the abundant amount of well-formed dolomite rhombs. Porosity is moderately developed throughout this sample.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6214 ft
Sample Number: 1-8R

Measured Porosity: 9.0%
Permeability (Klinkenberg): 9.31md
Grain Density: 2.81gm/cc

Lithology: Dolostone
Sedimentary Fabric: Obscured by diagenesis; some crystal size-zoning; pre-stylolitic seams

Dolomite Crystal Range: 0.02mm-0.30 mm
Dolomite Crystal Size: 0.15mm
Compaction: Moderate to High (pre-stylolitic seams)
Dolomite Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace (pore-lining)

Cement Types: Dolomite (abundant) as a replacement of rock groundmass; calcite spar (minor) fills vugs and molds; rare pore-filling gypsum

Porosity Types: Intercrystalline (both within regions of partial dolomite infilling of molds and true groundmass intercrystal pores); moldic pores are also common

Reservoir Quality: Fair to Good; decent interconnection of pores and moderate overall porosity

Magnification: A: 40X B: 200X

A) The low magnification survey photomicrograph features a slightly calcitic dolostone. Dolomite (tan) is dominant; calcite spar (stained red) mainly fills molds. Moldic areas not infilled retain pore space (blue). Minor organic material mixed with clay (appear dark).

B) This photomicrograph provides a magnified view of the pore-filling calcite spar and abundant dolomite. Porosity is moderately developed throughout this sample. Note detail of the authigenic clay/organic mix.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6218 ft
Sample Number: 1-9R

Measured Porosity: 6.2%
Permeability (Klinkenberg): 0.018md
Grain Density: 2.81gm/cc

Lithology: Dolostone
Sedimentary Fabric: Obscured by diagenesis; some crystal size-zoning; pre-stylolitic seams

Dolomite Crystal Range: 0.03mm-0.31mm
Dolomite Crystal Size: 0.15mm
Compaction: Moderate to High (pre-stylolitic seams)
Dolomite Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace (pore-lining)

Cement Types: Dolomite (abundant) as a replacement of rock groundmass; calcite spar (minor) fills vugs and molds; rare pore-filling gypsum

Porosity Types: Intercrystalline (both within regions of partial dolomite infilling of molds and true groundmass intercrystal pores); moldic pores are also common

Reservoir Quality: Fair; decent interconnection of pores and moderate overall porosity

Magnification: A: 40X B: 200X

A) The low magnification survey photomicrograph features a slightly calcitic dolostone. Dolomite (tan) is dominant; calcite spar (stained red) mainly fills molds. Intercrystalline areas not infilled retain pore space (blue). Minor organic material mixed with clay along stylotic seam.

B) This photomicrograph provides a magnified view of the moldic pore-filling calcite spar and abundant dolomite Porosity is poorly to moderately developed throughout this sample. Note the calcite filling pores between dolomite rhombs.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6222 ft
Sample Number: 1-10R

Measured Porosity: 2.3%
Permeability (Klinkenberg): 0.022md
Grain Density: 2.78gm/cc

Lithology: Dolomitic Limestone
Sedimentary Fabric: Obscured by diagenesis; stylolitic seams; some crystal size-zoning

Dolo. Crystal Range: 0.05mm-0.35mm
Dolo. Crystal Size: 0.20mm avg.
Compaction: High (stylolitic seams)
Dolo. Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace pore-lining

Cement Types: Dolomite; calcite spar

Porosity Types: Intercrystalline; occurs within regions of partial dolomite infilling of molds and as dissolution variety associated with stylolites

Reservoir Quality: Poor; limited pore space

Magnification: A: 40X B: 200X

A) The survey photomicrograph is a low magnification view, which displays a typical view of rock composition, which is dominated by calcite (red) with lesser dolomite (tan). Note the organic concentrations defining the jagged stylolitic seam. Porosity (blue) is poorly developed and only exist along the stylolitic seam..

B) The high magnification photomicrograph provides a magnified view along the stylolitic seam. Note the dark organic material comprising the seam. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6242 ft
Sample Number: 1-11R

Measured Porosity: 4.4%
Permeability (Klinkenberg): 0.0071 md
Grain Density: 2.81 gm/cc

Lithology: Dolomitic Limestone
Sedimentary Fabric: Obscured by diagenesis; stylolitic seams; some crystal size-zoning

Dolo. Crystal Range: 0.05mm-0.35mm
Dolo. Crystal Size: 0.20mm avg.
Compaction: High (stylolitic seams)
Dolo. Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace pore-lining

Cement Types: Pyrite; dolomite; calcite spar

Porosity Types: Intercrystalline; occurs within regions of partial dolomite infilling of molds and as dissolution variety associated with stylolites

Reservoir Quality: Poor to Fair; limited pore space

Magnification: A: 40X B: 200X

A) The survey photomicrograph is a low magnification view, which displays a typical view of rock composition, which contains generally equal amounts of calcite (red) and dolomite (tan). Note the organic concentrations (opaque) defining the jagged stylolitic seam. Porosity (blue) is poorly developed, overall, in this limestone.

B) The high magnification photomicrograph provides a magnified view of Porosity that is found in intercrystalline regions between well formed dolomite rhombs Note the dark organic material comprising the stylolitic seam. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.

GENERAL THIN SECTION DESCRIPTION
Evans No. 6
Haskell County, Oklahoma

Sample Depth: 6260 ft
Sample Number: 1-12R

Measured Porosity: 2.1%
Permeability (Klinkenberg): 0.0009md
Grain Density: 2.73gm/cc

Lithology: Dolomitic Limestone
Sedimentary Fabric: Obscured by diagenesis; some crystal size-zoning

Dolo. Crystal Range: 0.05 mm-0.15 mm
Dolo. Crystal Size: 0.10 mm avg.
Compaction: High (stylolitic seams)
Dolo. Crystal Sorting: Moderately Well

Clay Content:
Detrital Matrix: None
Authigenic Clay: Trace pore-lining

Cement Types: Calcite

Porosity Types: Intercrystalline; occurs within regions of partial dolomite infilling of molds and as dissolution variety associated with stylolites

Reservoir Quality: Poor; limited pore space

Magnification: A: 40X B: 200X

A) The survey photomicrograph is a low magnification view which displays a typical view of rock composition, which is dominated by calcite (red) with lesser dolomite (tan). Porosity (blue) is almost nonexistent.

B) The high magnification photomicrograph provides a magnified view of the area near in Plate 1A. Porosity is found in intercrystalline regions between dolomite rhombs Note the dark organic material comprising the stylolitic seam at F9. Calcite spar is abundant in this limestone and exists as both a cement and as replaced allochems.